WESTERN UNION Technical Review

TENTH ANNIVERSARY ISSUE

Fault Localisation in Submarine Telegraph Cables

Visualizing Transistor Principles

Loading Coils for Ocean Cables

Keying Loss in Telegraphy

Multiplex-Teleprinter Circuit

JULY 1957
VOL. 11 NO. 3

WESTERN UNION Technical Review

VOLUME 11
NUMBER 3

Presenting Developments in Record Communications and Published Primarily for Western Union's Supervisory, Maintenance and Engineering Personnel.

JULY 1957

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Published Quarterly by

THE WESTERN UNION TELEGRAPH COMPANY

Address all communications to THE WESTERN UNION TELEGRAPH CO., COMMITTEE ON TECHNICAL PUBLICATION, 60 HUDSON ST., NEW YORK 13, N. Y.

Subscriptions $1.50 per year

Printed in U.S.A.

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Tenth Anniversary

Just ten years ago, publication of the Western Union TECHNICAL REVIEW was started modestly with a first edition dated July 1947. As a point of interest, however, the REVIEW was under serious consideration more than two years earlier by the late F. E. d'Humy who wrote on February 3, 1944 (during World War II), to Western Union's former president, James L. Egan, "When I worked out the recently reorganized Engineering Department, I had in mind the helpfulness of an Engineering Magazine * * *. Such a publication could be made quarterly."

In ten years the REVIEW has become the most widely read telegraph engineering publication in the world with subscribers in some 40 countries. Numerous universities, public libraries, government agencies and business organizations now receive the REVIEW regularly.

In its four issues a year for the past ten years, the TECHNICAL REVIEW has published over 200 informative articles on telegraphy and allied subjects, primarily with reference to current technical developments. An occasional article, however, has provided historical background or other information of general interest to telecommunication workers. A tally shows 139 authors have contributed these manuscripts which have dealt with at least a dozen basic categories of telegraph science such as carrier and switching systems, ocean cables, facsimile techniques, microwave developments and the like.

In the foreword for the initial issue were some sound observations, as true today as they were when written:

"This, the first issue of the Western Union TECHNICAL REVIEW, inaugurates a project by which it is hoped that technically minded employees may become better informed regarding some of the fundamentals which underlie the technological progress of their company.

"Science and its practical application have revolutionized ways of living since Morse blazed the trail with his telegraph. In present day life, the needs of the public and competition force industry to search constantly for new ways and new products, and to utilize the latest results of scientific skill. Long ago the telegraph industry discarded the Morse key and sounder — its early symbol of distinction — to make way for modern methods.

"Mechanization is synonymous with progress. Electronics, facsimile and microwave radio have become commonplace in Western Union language and thinking. Changes in methods and facilities are taking place rapidly — so rapidly that there is need for a new medium to give the company's personnel a better understanding of the tools now being placed in use, and a better ability to use these tools easily and effectively.

"This TECHNICAL REVIEW is primarily intended for employees who are concerned with the installation, maintenance or operation of technical equipment. The publication will be issued quarterly and at first will constitute a medium for distributing reprints of technical papers which have been presented before engineering or scientific societies or published in established periodicals. Later it is planned to include specially written technical articles, and it is hoped that field employees as well as headquarters engineers will be counted among the authors.

"The Committee on Technical Publication, which will issue this periodical, will welcome comments and suggestions that may be helpful in the planning of future issues."

Although the Western Union TECHNICAL REVIEW continues to be published just as it was initially "primarily for Western Union's supervisory, maintenance and engineering personnel" its circulation has increased to 300 percent of the 1947 figure. Now for the next ten years!

R. A. GOODMAN, European Plant Engineer, London

D. A. PAWSON, Engineer, London

Fault Localisation in Submarine Telegraph Cables

Where there is exposure of the copper conductor to sea water, with comparatively low resistance at the fault, usual d-c test methods are quite adequate to locate submarine telegraph cable defects. In fact, some years ago studies showed that in every hundred fault localisations made by the cable stations, 42 came within half a mile of the actual position as found by the ships, with only 14 not predicted within two miles.

When a cable fault develops within ten or so miles of shore, the pulse-echo method may be used to advantage by cable stations but its chief application is aboard ship when cable is being picked up toward a fault of such resistance that the ship's ordinary testing equipment cannot distinguish between several miles away and a few hundred feet from the ship's bow. In such a case it is awkward for the ship to decide whether to put the cable through and then grapple for the fault further along the line, or to continue picking up. By means of the pulse-echo method the ship can reach out ten miles and determine rapidly and with reasonable certainty whether the fault is close aboard.

There have been instances of faults close to shore where ships have cut in some miles seaward on the basis of station tests and have picked up practically all of the cable in to the beach before coming upon the fault. This is costly in ship time and the extra handling of the cable does not improve its physical condition. If both the ship and the cable station have pulse-echo testing equipment the possibility of such miscalculation is virtually eliminated.

THE PURPOSE of this article is to describe the application of the pulse-echo method of electrical testing to the localising of faults in submarine telegraph cables. The principles of pulse-echo testing are well known, being similar to those of radar, but their application to submarine telegraph cables, and in particular to the Western Union transatlantic system, is a more recent development.[1]

In order to provide a background against which the merits of the new method can be assessed, a review is made of d-c methods of fault localisation hitherto commonly used in submarine telegraph work. These methods will indeed continue to be essential for faults which are distant from the testing station but for close-in faults—those within, say, ten nautical miles—are likely to be largely superseded by pulse-echo methods. The a-c impedance method of fault localisation is also discussed briefly for purposes of comparison.

The purpose of the d-c tests is to express the cable distance to the fault in terms of the conductor resistance or capacitance. Comparison of the test figures with the resistance or capacitance of the normal cable, which is known from records of laying and of subsequent repairs, permits calculation of the distance to the fault. The records are maintained to a high degree of accuracy, to within one part in a thousand, but the accuracy of the figures obtained from the localisation test is much dependent upon the nature of the fault.

Capacitance Bridge Test

In the case of a complete disconnection of the conductor unaccompanied by any failure of the insulation, measurement of the capacitance up to the fault by d-c methods is straightforward and permits localisation with high accuracy. The test commonly used is that devised by Gott and is in effect a d-c capacitance bridge test. For close-in faults adequate results are obtained from the direct deflection test, in which a comparison is made between the deflections of a ballistic galvanometer when charging first the cable

and then a known capacitance. In practice, open-circuit faults are relatively few; they are usually restricted to failures under tension of conductor joints of the soft-soldered scarfed type. Such joints are no longer made, but large numbers of them are still in service.

Many more problems and difficulties are presented by faults in which the insulation is affected and the conductor more or less exposed to the sea water, with or without complete rupture of the conductor itself. These constitute the large majority of all the faults encountered. Localisation by direct current involves resistance measurements and is complicated by variation in the apparent fault resistance due to polarisation effects and chemical changes at the exposure, some of which are dependent upon the intensity of the testing current. This dependence of the fault behaviour on the magnitude of the current passed through it into the sea water has been extensively studied and follows laws which have been established empirically over the years. Faults which are of high resistance or of an intermittent nature cannot be localised reliably by d-c methods and must be reduced to low and fairly constant values, usually by applying to the cable a sustained direct potential of negative polarity.

In addition to the variable resistance and emf of polarisation of the fault, there is commonly present a difference of potential between the sea water at the fault position and the sea water used for the ground connection at the testing station. This latter causes a so-called "earth current" to flow in the cable; if it is constant or varies but slowly it occasions no difficulty but a rapidly varying earth current is not infrequently encountered and may have appreciable effect on the accuracy of localisation of the fault.

Two Categories of Tests

D-c methods of fault localisation fall into two categories—one in which the apparent fault resistance is assumed to bear a definite relationship to the magnitude of the testing current and the other in which the fault resistance is inherently eliminated from the measurement. An example of the first kind of test is the Kennelly in which it is assumed that the fault resistance is inversely proportional to the square root of the testing current. Two successive Wheatstone bridge observations are made with different testing currents of known ratio (commonly four to one). Application of the inverse square root law to the two test results permits elimination of the fault resistance by calculation. Errors of measurement due to the presence of constant earth currents and polarisation potentials are avoided by balancing the Wheatstone bridge to false zero, i.e., to the galvanometer deflection produced by earth currents and polarisation effects when no testing battery is applied.

Another example of the application of an empirical testing current in relation to fault resistance law is provided by the commonly used Black test. A Wheatstone bridge is used to measure the resistance to earth up to and through the fault and provision is made for the ready insertion of resistance in the battery circuit to reduce the current through the fault in the ratio two to one, i.e., from I to $\frac{I}{2}$. The bridge is then adjusted until the same galvanometer deflection is attained for both values of testing current. The test is repeated with currents of $\frac{I}{2}$ and $\frac{I}{4}$ and again with still smaller values $\frac{I}{4}$ and $\frac{I}{8}$. From the resultant three bridge readings the resistance to the fault may be deduced by the application of an empirical correction which, for low fault resistances, corresponds closely to the assumption made for the Kennelly test as regards change of fault resistance with current. (See Appendix I.)

Typical examples of methods of measurement which inherently eliminate the fault resistance are the Varley Loop test and the Overlap test. In the former a second cable, without a fault, is required; the two are joined together at the distant cable station. Measurements are made of the loop resistance of the two cables and

of the difference between the resistances of the two paths presented by the loop to ground through the fault; from these measurements the fault resistance may be eliminated by calculation and the conductor resistance to the fault thus obtained. In the Overlap test only the faulty cable is required and measurements of the conductor and fault resistance, with the far end of the cable earthed, are made successively by the two cable stations. Resistance is added by the cable station nearer the fault until the resistances measured by both stations are the same. The resistance to the fault may then be calculated.

Skill, Judgment, Patience Needed

Every method of fault localisation by d-c resistance measurements depends upon a calculation involving the difference of two observed resistances and thus suffers the disadvantage of being very susceptible to determination errors in both of them. Again, earth currents vary slowly in a random manner and although, as far as circumstances permit, a period of least earth current activity is chosen for making a test, some degree of error from this cause is unavoidable. These factors make the successful localisation of the fault very dependent upon the skill, judgment and patience of the cable station or ship's electrician.

In the case of a distant fault, especially one in deep water, the accuracy of localisation, which is within, say, 10 ohms corresponding to a distance of between 3 and 6 miles depending on the conductor size, is commonly well within that to which the cable ship can navigate and grapple. When the fault is nearer the shore, however, say within 100 or 200 miles, the accuracy to which the repair ship can work is greater by reason of both the availability of radio navigational aids and the lesser depth of water in which grappling has to be done; the accuracy of the localisation tests, being much dependent upon the nature of the fault, is not greatly enhanced in comparison with that of the more distant faults, and is therefore a prominent factor affecting the amount of time and the length of stock cable which must be expended on the repair.

Leader gear[2] is commonly used by all ships to achieve greater accuracy in determining the fault position than is provided in the majority of instances by the d-c test results; it is invaluable for faults which are in depths less than 200 fathoms except for inshore and shallow water faults which the ship herself cannot reach with safety and for which it is of little practical application since leader work from boats is difficult and often unrewarding. In normal conditions leader gear observations permit determination of the fault position to within a quarter of a mile.

On the score of accuracy alone, therefore, d-c tests have distinct limitations, despite the high degree of skill and judgment which long experience has brought to their application. And, as has already been stated, they have the further disadvantage that they are of no avail for intermittent faults. There is thus an evident need for a method of localisation which is inherently independent of the nature and behaviour of the fault, especially for localisations within a few miles from the testing point. This need is even greater on a cable ship than at a terminal station, since in the course of the majority of repairs in which she is engaged the ship is faced with the necessity of determining the position of the fault with respect to the point at which the cable has been grappled and cut. Ease and speed of testing are of primary importance in all such cases and in this respect again d-c methods leave a good deal to be desired. It is in an endeavour to fulfill these requirements that pulse-echo testing has been applied in the Western Union cable system.

Echo Reflection Phenomenon

If an alternating potential is applied to a uniform transmission line terminated in an impedance differing from the line characteristic impedance, not all the energy arriving at the termination is absorbed there, some being reflected to travel back to the source. Use is made of this reflection phenomenon in the pulse-echo method of fault localisation.

The cable under test is considered to be

uniform; a fault appears as an impedance discontinuity from which an incident pulse is reflected producing an echo pulse at the testing point. In practice a succession of pulses is transmitted into the cable and the outgoing pulses and their echoes are displayed on the screen of a cathode ray tube. The interval between successive transmitted pulses is sufficient to allow the reception of the echo from one before the transmission of the next.

From a knowledge of the propagation velocity of the pulse (See Appendix II) and of the time delay between its transmission and the reception of its echo may be determined the distance to the fault. Similarly, knowledge of the relative amplitudes of the transmitted pulse and its echo, of the attenuation of the cable and of the relative polarity of the echo, enables the type and magnitude of the fault to be estimated.

A partial or complete break in the conductor, giving rise to an abrupt increase of impedance, produces an echo of the same polarity as the transmitted pulse, and an abrupt decrease of impedance, such as occurs at a leakage fault, an echo of the opposite polarity. The impedance discontinuity at a junction between two dissimilar cores obeys the same rule for polarity of echo: "like" for an impedance rise, "unlike" for an impedance fall.

In the design of an equipment for Western Union service, particularly for use on board cable ships, high importance was attached to the need for simplicity and speed of manipulation. The display unit is a standard commercial double beam oscilloscope with built-in amplifiers and calibrated time measurement controls; this and a specially constructed pulse generator unit comprise the whole equipment, which is illustrated in Figure 1.

The width of the transmitted pulse is dictated by range considerations; a maximum range of 10 nautical miles was considered to be adequate. A minimum pulse width of 1 μS was chosen as capable of giving fault indications as near as about 0.2 n.m. but the high attenuation of telegraph cables required that alternative widths of 5 μS, 10 μS and 20 μS be furnished for localisations at greater distances. The pulse repetition frequency selected was 3 kc/s for the 1, 5 and 10 μS and 1 kc/s for the 20 μS pulse.

A comparator is included so that the delay of an echo from, say, the open-circuited end of a good cable of known length in the ship's tank may be compared with the delay of the echo from the faulty cable under test. If the reference cable and the faulty one are of similar construction the distance to the fault is indicated directly on a meter. There will usually be cable of suitable characteristics among the spare stock carried on board; it has been established by trials that the velocity of propagation is the same whether the cable is coiled in tanks or laid along the sea-bottom.

Apparatus Circuitry

The schematic diagram of the apparatus is shown in block form in Figure 2. An asymmetrical multivibrator generates rectangular pulses of duration about 15 μS and repetition rate either 1 kc/s or 3 kc/s. The leading edge of each pulse is used to trigger the timebase of the cathode ray oscilloscope. The trailing edge triggers a Kipp relay valve (12AU7 vacuum tube)

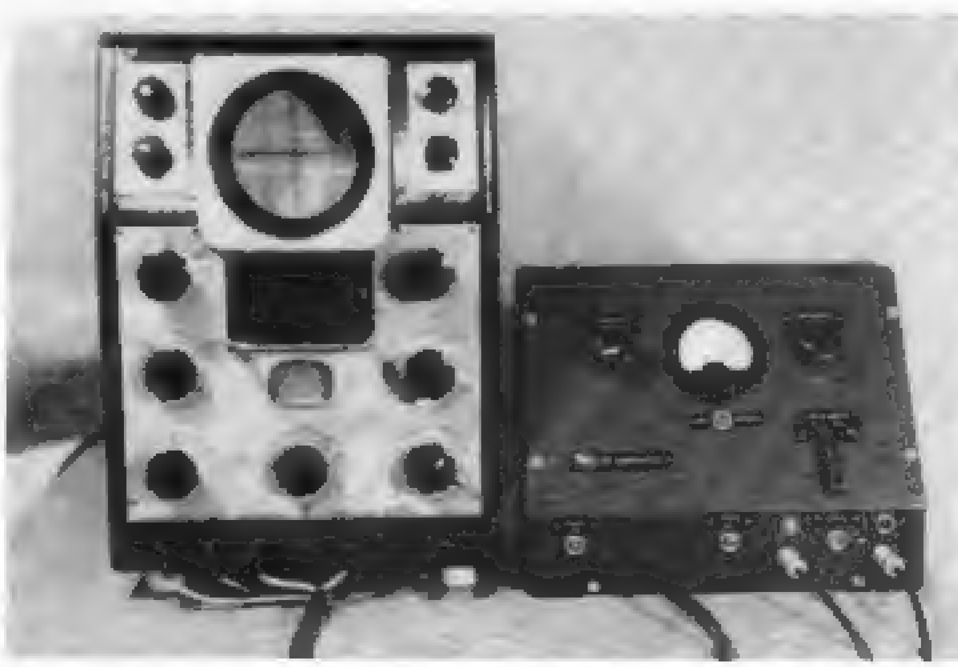

Figure 1. Display unit for use on board ship

which generates positive-going rectangular pulses of nominal duration 1 μS, 5 μS, 10 μS or 20 μS. (The switch controlling the pulse width also controls the pulse repetition rate.) The output from the Kipp relay valve is taken to the output stage of the generator—two beam tetrodes in parallel connected as a cathode follower. The positive-going output pulse from this low-impedance source has an amplitude of about 12 volts and is delayed by about 15 μS with respect to the oscilloscope trigger. The delay of 15 μS enables the commencement of the transmitted pulse to be seen on the oscilloscope and avoids errors which might be caused by nonlinearity of the initial part of the oscilloscope sweep.

The output of the pulse generator is connected to the cable under test and also, in parallel with the cable, with the oscilloscope. In series with the oscilloscope is a low-frequency filter and an amplitude limiter. The filter reduces the effect on the oscilloscope trace of any extraneous low-frequency disturbance which may be present in the cable; the amplitude limiter, consisting of a biased germanium diode, limits the amplitude of the oscilloscope deflection produced by the transmitted pulse but has no effect on that of the much smaller echo.

The comparator circuit makes use of a simple analogue computer technique. The mean value of a series of rectangular pulses, at a constant repetition rate, is proportional to the product of the pulse amplitude and the pulse width. The distance to the point of echo in the cable is equal to the product of the velocity of propagation of the pulse and half the time period between the transmission of the pulse and reception of the echo. Therefore a moving-coil meter may be made to give a deflection proportional to the distance to the point of echo if the meter is fed with repeated rectangular pulses of duration equal to the echo delay time and of amplitude proportional to the velocity of propagation.

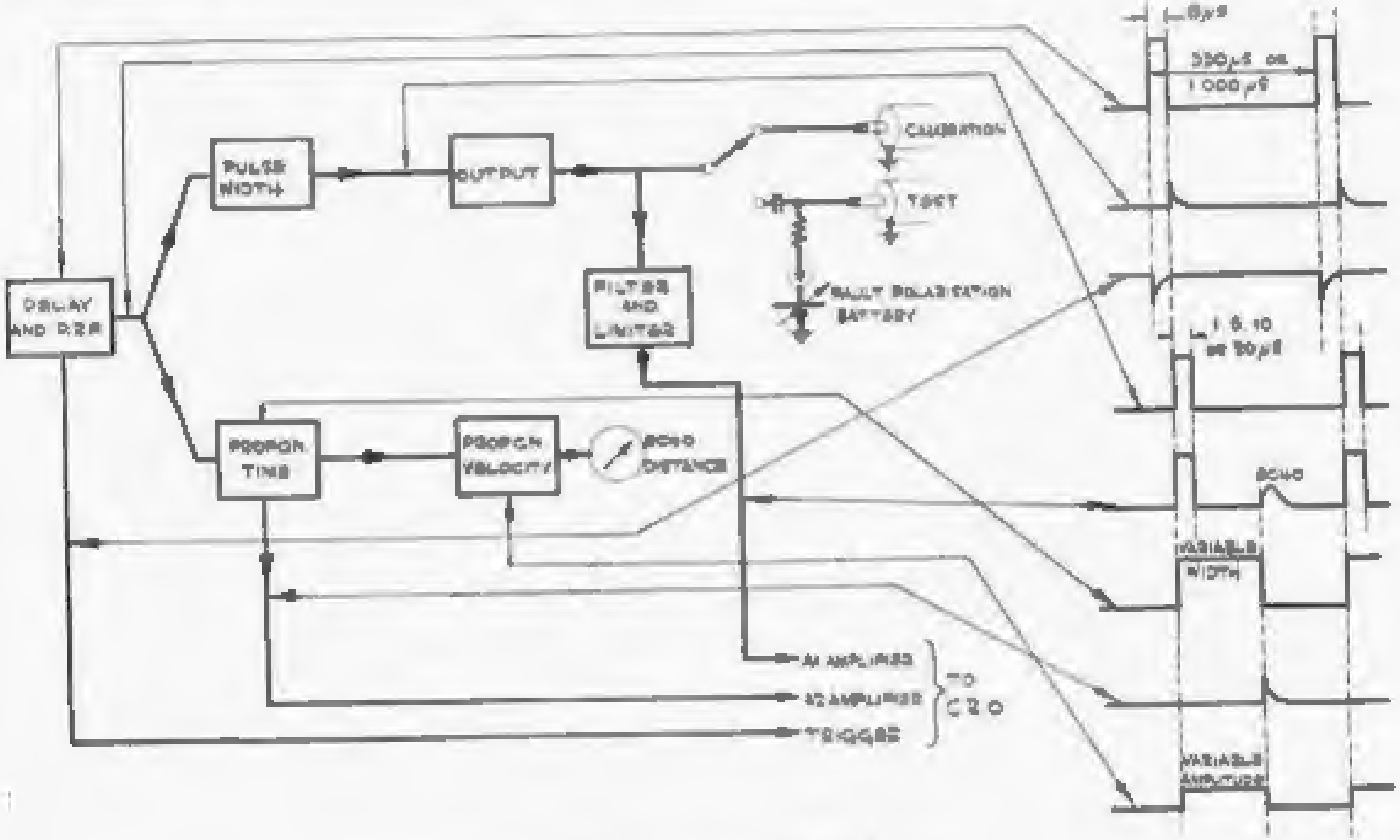

Figure 2. Pulse generator—block diagram

Accordingly an additional Kipp relay valve is triggered at the same instant as the transmitted pulse generator valve and produces a rectangular comparator pulse of duration adjustable by the "Propagation Time" control. The trailing edge of this pulse is differentiated to form a marker pulse which is fed to the second amplifier and trace of the oscilloscope. The comparator pulse is also fed to a bi-

stable Eccles-Jordan trigger circuit which permits adjustment of the amplitude of the pulse independently of its duration. A moving coil milliameter, calibrated in nautical miles, is shunted by a variable resistor, the "Propagation Velocity" control, and connected in one anode of the Eccles-Jordan trigger pair. The meter scale is calibrated in nautical miles, 0 — 10.

To use the comparator, the transmitted pulse is sent into the reference cable, the propagation time control adjusted so that the marker pulse on the second trace of the oscilloscope coincides with the echo from the end of the cable on the first trace, and the propagation velocity control set to produce a meter deflection corresponding to the known length of the reference cable. The transmitted pulse is then switched to the faulty cable and the propagation time control is readjusted to move the marker pulse to the position of the fault echo. The deflection of the meter then indicates directly the distance to the fault.

Measurement Techniques

The shape of the echo pulse differs considerably from that of the transmitted pulse; the cable attenuation and the propagation velocity increase with frequency so that the components of the rectangular outgoing pulse become both changed in amplitude and displaced in time relative to one another. In particular the front of the pulse becomes rounded and its point of commencement less well-defined. Determination of the time of travel of the pulse out to the fault and back is made by measuring the time interval between the sharp leading edge of the transmitted pulse and the point at which the echo pulse becomes just perceptible as a deviation from the oscilloscope trace zero line.

Typical oscilloscope records of the echoes produced at the distant ends of short lengths of cable are shown in Figure 3. In each of examples (a), (b) and (c) the cable is of one type throughout; (d) shows the additional echo produced at the junction of two pieces of cable of different sizes of which the test length was composed. These echoes from what must be regarded as normal discontinuities (such junctions abound in telegraph cables) may be useful for identification purposes but tend to limit the effective range of the equipment for fault localisation since they may distort succeeding echoes, thereby giving unreliable

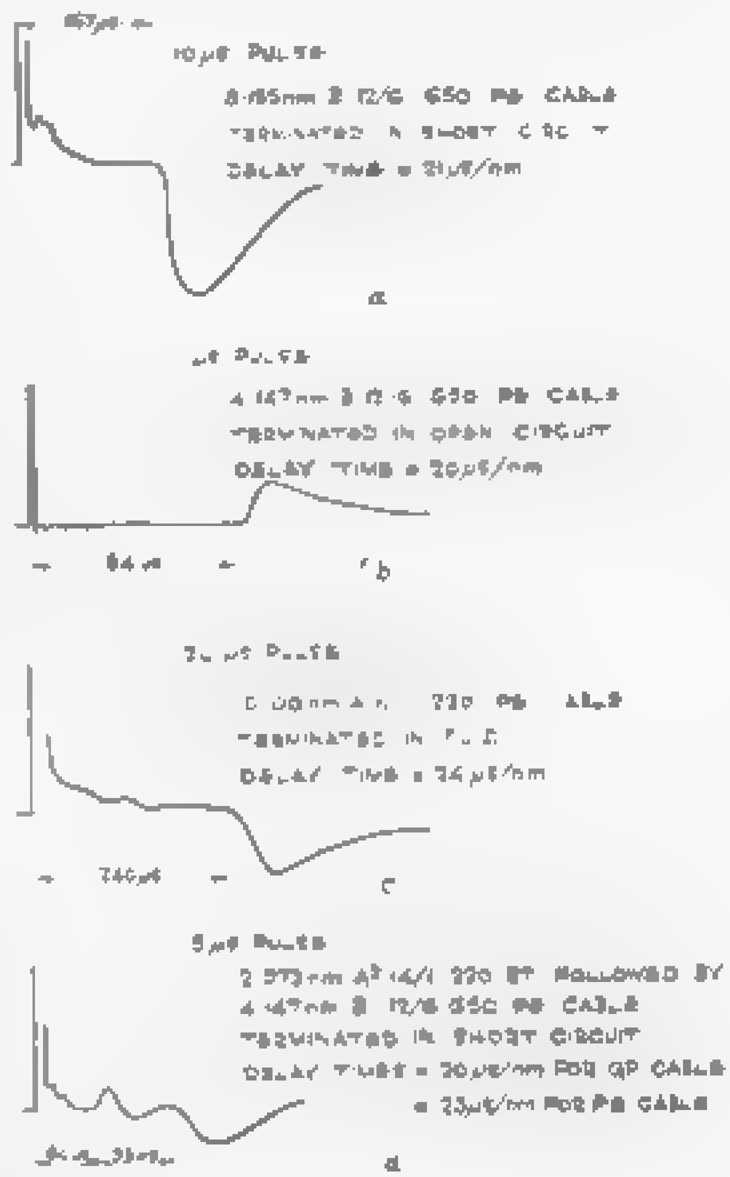

Figure 3. Pulse-echo fault localisation—typical echoes

time measurements, and reflect energy, thus reducing the size of the echo from a more distant discontinuity.

When used at a shore station the pulse testing equipment is applied as near to the actual shore end of the cable as possible. In some cases this is essential as the impedance of the land cable from the cable station to the beginning of the submarine section is so drastically different from that of the submarine section that the junction of the two would reflect a large proportion of the incident pulse energy and thus produce an echo strong enough to swamp any that might be reflected from the cable itself.

A special instance of a normal discontinuity is encountered in observations on a shore end which contains one or two earth cores in addition to the line core. At the positions of each sea-earth termination an echo is produced in the line by the impedance discontinuity resulting from the termination of the adjacent core. As would be expected this effect does not occur if the cores are lapped with anti-teredo brass tape, which then forms a return path for the pulse current.

The fact that the resistance of a cable fault changes in general with the magnitude and polarity of a direct current which is passed through it is of primary importance in d-c testing; it may also be utilised with advantage in pulse-echo tests by applying to the cable a direct current simultaneously with the transmitted pulse. The method of doing so is shown in Figure 2. By varying the direct current and observing the resulting effect on the oscilloscope trace, the position of the fault echo may be clearly established even in

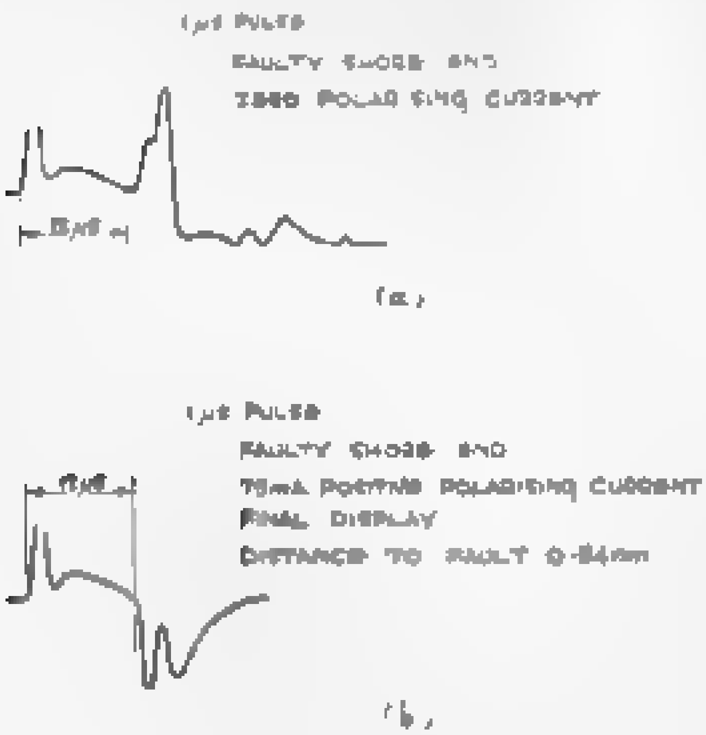

Figure 4. Pulse-echo fault localisation—typical fault

the presence of a number of other echoes caused by normal discontinuities in the cable. This procedure is of value in the majority of fault localisation tests. Fault echoes using the pulse-echo equipment with a superimposed d-c polarising current are shown in Figure 4. The initial echo is due to the fault in the line and the second is due to one of the adjacent cores being terminated in the short sea earth. The distance to the fault was derived by comparison of the echoes from the line and short sea-earth cores and gave a localisation accurate to within three fathoms.

The results obtained with the pulse-echo equipment have shown that the velocity of propagation of short-duration pulses in telegraph cables is somewhat lower for polythene insulated cores and somewhat higher for gutta-percha cores than that calculated in Appendix II. The size of the core has some effect on the velocity in cables of similar dielectric, as has the presence or absence of antiteredo tape. Measurements of the double propagation time for cables such as those in the Western Union system yield values of about 22 μS/n.m. for polythene insulated core and about 19 μS/n.m. for gutta-percha insulated core. Whenever possible, in a practical localisation test, the distance to the fault should be expressed in terms of a known length of similar cable upon which observation can be made at the same time—for a ship, a length of stock cable in her tanks, and for a shore station, such spare sea-earth cores or other good sections as may be available.

The A-C Impedance Method

As an alternative to the pulse-echo method of fault localisation, use might be made of the a-c bridge method whereby an impedance-frequency graph for the cable is constructed from a series of bridge readings over a range of transmission frequencies. The presence of a discontinuity in the cable is then indicated by a succession of maxima and minima in the curve and the distance to the fault may be deduced in the manner indicated in Appendix III. However, application of this method to submarine telegraph cables offers fewer advantages than may be derived from the pulse-echo method, within the range of distances for which the latter can provide (whereby the necessary observations and the analysis thereof are much more rapidly and easily made) particularly when normal discontinuities are

On board C. S. "Lord Kelvin," Chief Electrician Edward O'Donoghue, at whose original suggestion the pulse-echo technique was adapted for use on Western Union ocean telegraph cables, views the equipment comprising an oscilloscope (left), pulse generator (right), and polarizing circuit equipment (above). Fault indications generally have been extremely accurate, sometimes to within a few fathoms. If similar good cable of known length is aboard ship, the echo delay of a faulty cable may be checked against that of the good cable by direct comparison.

present in addition to the one which is being localised.

The comparative economy of time and effort is likely to be of particular importance on board ship, when, as is more often than not the case, circumstances call for the localisation of the fault in a picked-up cable with minimum delay to the ship's operations. The pulse-echo method has the additional and unique advantage of giving a reliable indication of the position of an intermittent fault.

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[illegible] Western Union Technical Review [illegible]

APPENDIX I

The Black Test for Fault Localisation

No record has been found of a detailed analysis of the fault localisation procedure now generally known as the Black test. It was described originally by R. Rolland Black in an article under the title "The Reduced Current Method for Localising Fractures in Submarine Cables" published in THE ELECTRICIAN (London) April 7, 1911.

In comparing his test with the false zero Kennelly method Black stated, "If current through the exposure were reduced instead of being cut off altogether, then the depolarisation will be only slightly reduced in accordance with the value of the reduced current, and then will remain constant", which is the basis of his technique. The following analysis of the Black test by Messrs. Goodman and Pawson is relevant to this discussion of fault localisation.

THE BASIC circuit employed in this test is shown in Figure 5. E_1, E_2 are chosen so that the corresponding currents, I_1, I_2 through the cable and fault are in a given ratio; e is the fault and earth emf and S the total resistance of the cable and fault. R is adjusted so that the out-of-balance voltage V is the same when either E_1 or E_2 is applied.

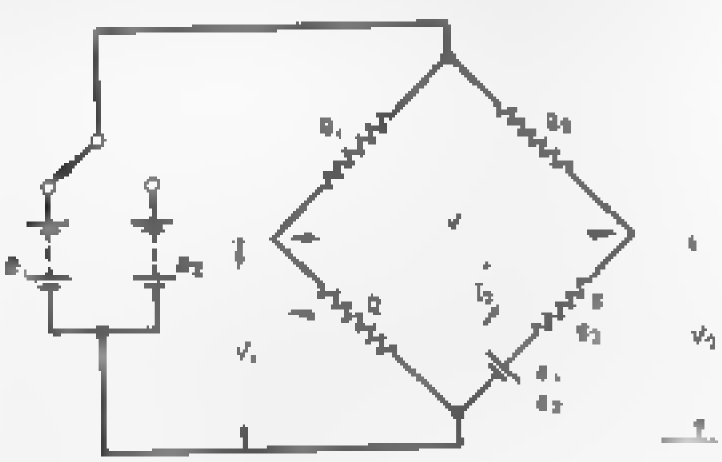


Figure 5. Black localisation test—theory

Applying E_1 to the circuit, the cable and fault have a resistance S_1 and emf e_1

$$V_2 = I_1 S_1 + e_1$$

$$E_1 = V_2 + I_1 R_2$$

$$= I_1 (S_1 + R_2) + e_1$$

$$V_1 = \frac{E_1 R}{R + R_1}$$

$$= \frac{[I_1 (S_1 + R_2) + e_1] R}{R + R_1}$$

$$V = V_1 - V_2$$

$$= \frac{[I_1 (S_1 + R_2) + e_1] R}{R + R_1} - (I_1 S_1 + e_1)$$

Similarly applying E_2 to the circuit, the cable and fault have a resistance S_2 and emf e_2 and

$$V = \frac{[I_2 (S_2 + R_2) + e_2] R}{R + R_1} - (I_2 S_2 + e_2)$$

Equating expressions for V with either E_1 or E_2 applied,

$$R = \frac{R_1}{R_2} \left(\frac{I_1 S_1 - I_2 S_2}{I_1 - I_2} + \frac{e_1 - e_2}{I_1 - I_2} \right)$$

Putting $I_2 = nI_1$

$$R = \frac{R_1}{R_2} \left(\frac{S_1 - nS_2}{1 - n} + \frac{e_1 - e_2}{I_1 (1 - n)} \right)$$

If the fault emf and the earth current are constant throughout the test then $e_1 = e_2$ and R is independent of their magnitude

$$R = \frac{R_1}{R_2} \left(\frac{S_1 - nS_2}{1 - n} \right)$$

Now

$$S = x + r$$

Where x = cable resistance to fault

r = variable fault resistance

Giving

$$S_1 = x + r_1$$

$$S_2 = x + r_2$$

Hence, putting $R_1 = R_2$

$$R = x + \frac{r_1 - nr_2}{1 - n}$$

Two such values of R are required, obtained with fault currents of I, nI and nI, n^2I, to localise the fault although a third value, with currents of n^2I, n^3I, is usually obtained for checking purposes.

Putting $R = A$ for the test with currents of I, nI

$R = B$ for the test with currents of nI, n^2I

$$A = x + \frac{r_1 - nr_2}{1 - n}$$

$$B = x + \frac{r_2 - nr_3}{1 - n}$$

Let it be assumed that

$$x = A - P(A - B)$$

i.e., that the resistance to the fault is given by deducting from the higher test reading a function of the difference between the two readings which is thus a function of the fault resistances only

Substituting for A and B in the above expression gives,

$$A - P(A-B) = x + \frac{r_1 - nr_2}{(1-n)}$$

$$- P\frac{[r_1 - r_2(1+n) + nr_3]}{(1-n)}$$

$$= x \text{ if } P = \frac{r_1 - nr_2}{r_1 - r_2(1+n) + nr_3}$$

The standard Black test procedure is to put $n = 2$.

$$\text{Then } P = \frac{r_1 - 2r_2}{r_1 - 3r_2 + 2r_3}$$

If it is further assumed (as for the Kennelly test) that the fault resistance is inversely proportional to the square root of the testing current

Then

$$r_1 = \frac{K}{I^{1/2}}, \quad r_2 = \frac{K}{\sqrt{2}I^{1/2}}, \quad r_3 = \frac{K}{2I^{1/2}}$$

Substituting for r_1, r_2 and r_3 gives.

$$P = 3.41 \text{ or}$$
$$x = A - 3.41\,(A - B)$$

In the standard table of coefficients prescribed for the Black test, the value given to P ranges between 3.45 and 3.09 as the difference between the test readings $(A-B)$ ranges between 2.5 ohms and 20 ohms, the coefficient being greater for the smaller differences. This table was compiled from the results of a large number of actual tests. The departure it represents from the assumption that the resistance of a fault varies inversely as the square root of the intensity of the testing current is quite small, however; the values given for P in the table correspond to ratios of fault resistance which lie within the limits represented by:

$$r = \frac{K}{I} \text{ and } r = \frac{K}{I}$$

APPENDIX II

Submarine Telegraph Cables at High Frequencies

A rectangular pulse of a few microseconds duration repeated at a fairly low frequency, i.e., at a few kilocycles per second, may be regarded as being mainly composed of a series of sinusoidal components of frequencies lying in the high-frequency range. At these high frequencies the distributed resistance and leakance of a cable may be assumed to be negligible compared with the distributed inductive and capacitative reactance. The equation for the characteristic impedance of the cable then simplifies to:

$$Zo = \sqrt{\frac{L}{C}}$$

Where Zo = Characteristic impedance of cable

L = Distributed inductance per unit length

C = Distributed capacitance per unit length

i.e. the characteristic impedance is resistive and independent of frequency

At high frequencies a submarine telegraph cable approaches a coaxial cable in behaviour, the return path being more or less concentrated around the insulation. The inductance and capacitance of a coaxial cable are readily calculated from the dimensions and electrical constants; hence substituting in the above expression

$$Z_o = \frac{1}{2\pi} \log_h \left(\frac{b}{a} \right) \sqrt{\frac{4\pi \times 10^{-7}}{\epsilon}} \text{ ohms}$$

Where b = diameter over cable insulation
a = diameter over cable conductor
ϵ = dielectric constant of cable insulation (M.K.S. units)

This equation gives approximate characteristic impedances for typical submarine telegraph cables of

Core 650/325 PE $Z_o = 33$ ohms
Core 220/170 PE $Z_o = 42$ ohms
Core 130/130 GP $Z_o = 37$ ohms

Similarly, V, the velocity of propagation of the cable at high frequencies, is given by

$$V = \frac{1}{\sqrt{4\pi \times 10^{-7}\epsilon}} \text{ km/sec.}$$

This equation gives velocities of propagation of about 105,000 and 90,000 nautical miles per second for polythene and gutta-percha insulated cables respectively.

The attenuation is proportional to the resistance to the conductor and return path. The majority of the current in the central conductor flows in its outer skin. In telegraph cables no special precautions are taken in design or manufacture to preserve a smooth surface on this conductor, and the return path resistance is also relatively high. The attenuation is therefore great; that of type 650/325 PE cable has been found to be of the order of 3 db per nautical mile for a $1\ \mu S$ rectangular pulse.

APPENDIX III

Fault Localisation by A-C Impedance Measurements

Reflection of an applied continuous a-c wave from the termination of a uniform transmission line, if the termination differs from the line characteristic impedance, alternately aids and opposes the applied wave as the frequency is varied. Thus the impedance frequency curve for a faulty cable will exhibit minima and maxima alternately. If the velocities of propagation are known for the frequencies at which successive maxima (or minima) occur, the distance to the fault may be calculated. Two successive maxima represent a phase change of 2π radians in the incident and reflected waves, hence if

f_1 = frequency at which first impedance maximum occurs

β_1 = phase change per unit length of transmission line, at frequency f_1

f_2 = frequency at which next impedance maximum occurs ($f_2 > f_1$)

β_2 = phase change per unit length of transmission line, at frequency f_2

l = distance to fault

Then

$$2\beta_2 l - 2\beta_1 l = 2\pi$$

$$\text{or } l = \frac{\pi}{\beta_2 - \beta_1}$$

Also, since V, the velocity of propagation, is given by $V = \frac{2\pi f}{\beta}$

$$l = \frac{V_1 V_2}{2(V_1 f_2 - V_2 f_1)}$$

Thus, determination of l calls for calculation of β_1 and β_2, or V_1 and V_2, from the primary constants of the cable, after the appropriate frequencies f_1 and f_2 have been found by measurement.

R. A. Goodman entered the service of the Western Union cable system in 1916 at London, England. After early experience as a telegraph operator and traffic maintenance electrician at terminal offices and cable stations, he joined the engineering staff of the European division in 1924, and has since been closely connected with developments in the manufacture, installation, operation and maintenance of cables and equipment in our transatlantic plant. He is a Bachelor of Science (Engineering) of London University and a Member of the Institution of Electrical Engineers. In 1951 Mr. Goodman took control of all plant and engineering activities in Europe, with the title of European Plant Engineer.

D. A. Pawson received his Bachelor of Science (Electrical Engineering) degree from the University of London in 1951, having previously served in the British Army and with Marconi's Wireless Telegraph Company. After graduation he joined the office of the European Plant Engineer, London, and has subsequently taken part in the modernization of the European section of the ocean cable system and in the manufacture of submarine telegraph cable. Mr. Pawson is a Chartered Electrical Engineer and an Associate Member of the Institution of Electrical Engineers.

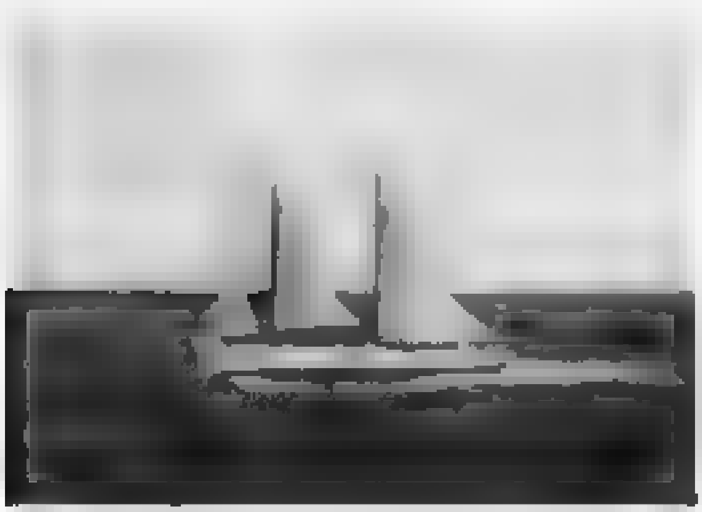
Cable Gear for the Schooner "Western Union"

The Telegraph Construction & Maintenance Company, London, is more conveniently called "Telcon"—the name used in this story reprinted from TELCON MAGAZINE.

Cyrus Field's first Atlantic cables were made by The Gutta Percha Company and Glass Elliott which combined in 1864 to form "Telcon." Since then submarine materials for use all over the world including Western Union's transatlantic loaded cables, have been produced by "Telcon."

IN 1954 a hauling gear was designed and built by Telcon for use by The Western Union Telegraph Company in their cable depot at Halifax, Nova Scotia.

Following their acceptance of that machine, they invited us to provide another essentially similar, as a picking up and paying out gear for their cable-laying schooner "Western Union" which is stationed at Key West, Florida, and for use on cables in the shallow waters off the Florida coast and in the West Indies. This



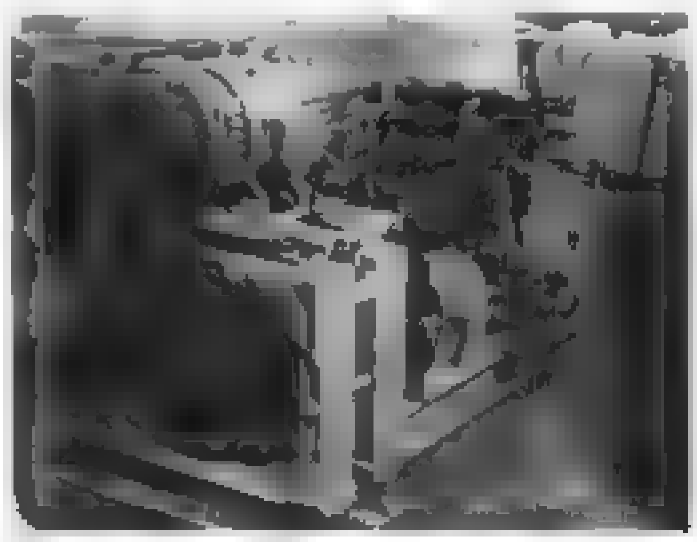
The Key West cable schooner "Western Union" as seen from the S. S. "Lord Kelvin" during a Bell Laboratories operation in the Bahamas, March 1948

called for very careful design owing to the weight restriction and the very limited space available. The layout is as follows:—

The power unit, situated in the engine room, consists of a Crompton Parkinson Exciter mounted immediately over the generator and connected to it through a vee belt drive. The generator and exciter are driven by a Ford Zephyr Industrial Type engine developing 31 B.H.P. with the governor set for 1900 R.P.M.

Power from the generator is fed through an Allen West Main Type contactor control panel, which is totally enclosed in a sheet steel case of drip proof construction also mounted in the engine room. This panel gives Ward-Leonard control to the Crompton Parkinson D.C. 16 h.p. main motor fitted to the main hauling gear on the ship's deck.

The cable drum, 4 ft. 6 in. in diameter and 12 in. between flanges, is driven by the 16 h.p. electric motor through a double reduction worm gear unit having a ratio of 280:1. The motor is forced-draught ventilated by means of a self-



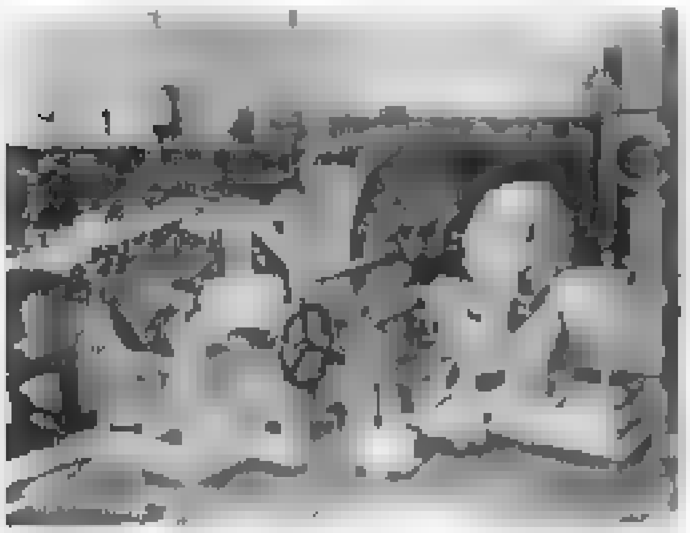
Petrol engine and generator

contained, electrically driven air blower unit fitted to the air inlet, suitable inlet and exhaust ducting being provided. The speed range of the main motor is 0–500 R.P.M. by generator voltage control against constant torque and 500–2000 R.P.M. by air motor shunt field regulation against constant horse power. A combined slipping and holding water-cooled brake is fitted to the drum and is controlled by a screwdown mechanism.

Push button switches for "Forward", "Reverse", "Accelerate", "Retard" and "Stop" are grouped within easy reach of

the operator of the hauling gear. The main motor is capable of holding a load of up to 5 tons stalled for a period of 5 minutes without overheating, and an alarm bell rings automatically to ensure that this period is not exceeded

A dog clutch is provided between the main drive and the cable drum and a fleeting knife assembly is fitted on the forward side of the drum. The draw-off gear is fitted with a jockey arm and length indicator and four jockey wheels for varying sizes of cable are supplied This draw-off gear is driven by bevel gears from the main reduction unit and a hand wheel is fitted for raising and lowering the jockey arm



General view of the cable gear

The acceptance tests were carried out on February 25 in the presence of Mr R. A. Goodman, European Plant Engineer of The Western Union Telegraph Company and his staff The gear was mounted on a temporary concrete test bed on the main wharf at Telcon Works, Greenwich. A 1 4 mile length of cable Type A 3-14 0 was used in conjunction with a Duckham ring gauge to indicate cable tension and three Telcon lorries provided the tractive effort when testing the braking capacity of the gear and also retardation when testing its hauling capacity

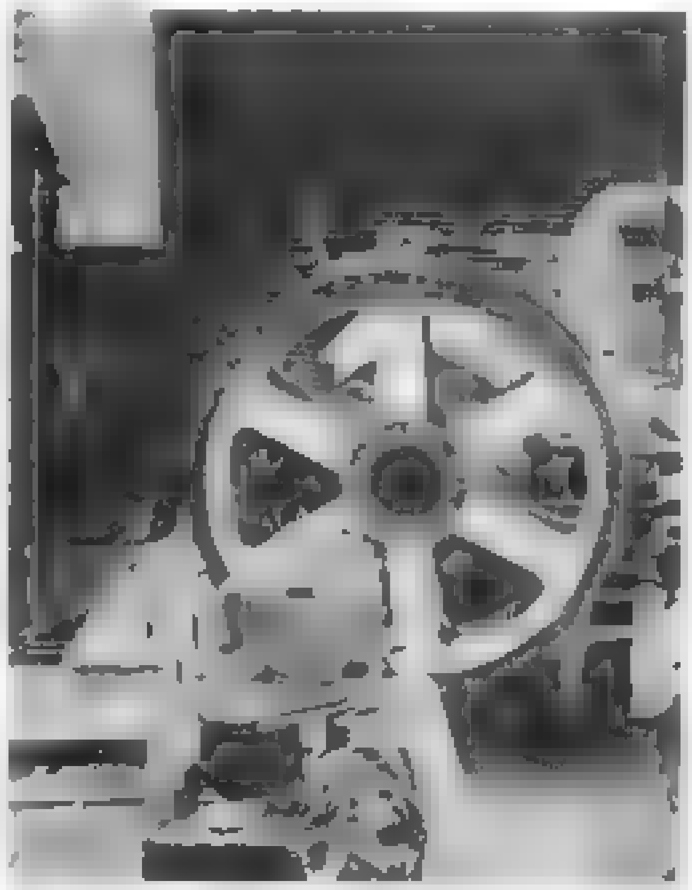
The following tests were carried out to the satisfaction of The Western Union Telegraph Company—

(*a*) Hauling at a quarter knot against a tension of 5 tons

(*b*) Hauling at 1 knot against a tension of 1 1 4 tons.

(*c*) Holding stationary against a tension of 5 tons for 5 minutes with the motor stalled and brakes off

(*d*) Holding against a tension of 5 tons with the brakes applied and the motor disconnected at the clutch



The cable drum

(*e*) Paying out at a tension of 3 tons at 2 knots with brakes applied and with motor disconnected at the clutch

We are indebted to The Western Union Telegraph Company and Bell Laboratories for permission to reproduce the photograph of the schooner "Western Union." We also wish to acknowledge the whole-hearted co-operation received from the officials of The Western Union Telegraph Company during the execution of the order

OSCAR E. PIERSON,* Project Engineer, Automation

Visualizing Transistor Principles

Because transistors are small, simple and efficient, these semiconductor amplifiers are especially well suited to telecommunications requirements and now are being employed quite generally in new telegraph circuitry. Oftimes, transistors replace vacuum tubes but they also make possible new circuit achievements not attainable with vacuum tubes.

Utilization of vacuum tubes in the fifty years since DeForest made the first triodes has been prodigious. Possible applications for transistors, not only in communications equipment but also in computors, data processing machines and automatic controls are unpredictably vast; however, "one doesn't have to understand *why* transistors work to use them — but it helps.

Inasmuch as the author had not arranged the manuscript for publication, this was done by W. Dale Cannon whose competent and gracious assistance is gratefully acknowledged by the Review.

In this article a simplified form of transistor theory is discussed which should be found useful to many who desire only a practical understanding of the principles of operation. The more precise theory is based on the methods of wave mechanics and is formulated in mathematical symbolism which cannot be represented by visualizable concepts. While this lack may be of no consequence to the physicist engaged in transistor development the average person generally prefers a more tangible theory, one which permits some form of mental imagery. An attempt is made herein to present such a theory while, at the same time, not departing too seriously from the requirements of accuracy.

Fundamentals of Current Conduction

The best known form of electric conduction is that in which the electron serves as the carrier for transporting charge through the conductor. Electrons are designated as negative carriers since each has a negative charge of 1.602×10^{-19} coulombs. Thus a current of one ampere corresponds to the motion of $(1.602 \times 10^{-19})^{-1} = 6.24 \times 10^{18}$ electrons per second through the conductor. This type of conduction is characteristic of metals such as copper, for example. The copper atom has 29 electrons surrounding the positive core or nucleus. They are grouped about the nucleus in the form of concentric shells of increasing radius. The electrons in the outermost shell of any atom determine largely the chemical characteristics of that atom and are known as its valence electrons. The valence electrons are not bound as tightly to the atomic core as are those in the inner shells.

The outer or valence shell of the copper atom contains only one electron, the other 28 are in shells closer to the nucleus, of which 2 are in the first shell, 8 in the second, and 18 in the third. The single valence electron is bound so loosely that it readily escapes and becomes a "free" electron. In this state it wanders about erratically among the copper atoms. The weak force which tends to attract it to an atom influences its motion very little. An atom which has lost one of its outer electrons is said to be ionized, that is, it has acquired a positive charge equal to the negative charge of the electron. The net charge within the conductor, however, remains at zero regardless of the number of free electrons. The positively charged ion is immobile and does not enter into the conduction process. This differs from the case where the conductor is a liquid (electrolytes) since here the ions are not

*Deceased

held firmly but are capable of drifting through the solution when a potential is applied. Electrolytes, therefore, have ionic as well as electronic carriers, the ions moving towards the negative side of the applied potential and the electrons towards the positive. Ionic conduction alters the structural arrangements of the ions in the conductor and since it does not normally occur in solid conductors (at least not to any significant degree) we will not consider it further

An estimate of the number of free electrons in a copper conductor may readily be made from the relation,

$$n = \frac{Nd}{A}$$

where n is number of atoms per cubic centimeter

N is Avogadro's number (the number of atoms per gram-atom) $= 6.023 \times 10^{23}$

d is the density of the conductor in grams per cc

and A is the atomic weight.

For copper we have $d = 8.89$

$A = 64$

$$\text{Hence } n = \frac{6.023 \times 10^{23} \times 8.89}{64} = 8.37 \times 10^{22}$$

atoms per cu. cm. If every atom were ionized there would consequently be 8.37×10^{22} free electrons per cubic centimeter, that is, approximately one free electron per 1.2×10^{-23} cubic centimeters of volume

If the cubic centimeter of copper were drawn out into a wire 20 centimeters in length and 0.05 square centimeters in cross-sectional area (approximately the size of a No. 10 B&S wire) there would be 4.18×10^{21} free electrons per centimeter of length. A current of one ampere flowing in this wire would require that the electrons move at a rate of

$$\frac{6.24 \times 10^{18}}{4.18 \times 10^{21}} = 1.5 \times 10^{-3} \text{ centimeters per}$$

second. At this rate it would require over 3-1/2 hours for a particular electron entering one end of the wire to traverse the 20-centimeter conductor. The motion referred to is the "drift velocity," i.e., that component of the electron's motion which

Another article, about the practical application and use of transistors, will be published in the Review at an early date.

is parallel to the applied electric field. The electron has other components of velocity which are much greater but since these do not contribute towards the flow of current they need not be considered

While the electrons themselves move at a practically imperceptible rate in the direction of current flow, a signal pulse injected at one end moves down the conductor at a velocity which in some cases may approach the speed of light. If an electron were injected at one end of the conductor another electron would leave the other end at practically the same instant. This is due to the tremendous electrostatic forces which act between the electrons. These forces are so great that the free electrons within the conductor have the characteristics of an incompressible fluid. Any attempt to push them into closer proximity brings these forces into play The slightest movement of an electron at one end is immediately transferred down the conductor so that all electrons move as if rigidly attached to each other Should we attempt to push more electrons into the conductor (by connecting one end to a source of potential and leaving the other end open) the space charge would rise so rapidly that many thousands of applied volts would hardly increase the electron density by a measurable amount.

Attempting to increase the number of carriers by this brute-force method is somewhat like attempting to force water into a closed pipe by applying pressure at the open end. It is likewise impossible to reduce the number of carriers by the application of a positive potential. The withdrawal of a relatively few electrons from the conductor would immediately cause the space charge to rise to a positive value which would quickly equalize the applied potential and prevent further removal of electrons.

This is a most important consideration and one which is closely related to the physical theory of transistors. Conductiv-

ity is a function of the number of available carriers (together with a factor known as "mobility"). If this number could be varied by some means which would not require much expenditure of energy, power gain would obviously be obtained. We see from the foregoing, however, that in a metallic conductor such as copper this is virtually impossible. The forces set up by space charge are barriers which permit no departure from the rule that the net space charge must always equal zero.

Consider the Vacuum Tube

The vacuum tube is an example of a device in which the carrier concentration is altered (and thus the conductivity) without large expenditures of power. The stream of electrons moving between cathode and plate is in effect a conductor whose conductivity is measured by the number of electrons traversing the intervening space. By causing the stream of electrons to pass through the grid structure its concentration may readily be controlled electrostatically by signal voltages applied to the grid. The positive at the plate is effectively in equilibrium with the sum of the negative space charge of the stream of electrons and the negative charge applied by the grid. If the grid becomes more negative, the electron space charge must reduce to maintain the balance, and conversely. Thus the concentration of the electron stream (plate current) varies inversely with the rise and fall of the negative grid potential. This is a well-known principle in the case of vacuum tubes and it is mentioned here merely to point out that the principle is general and other methods of applying it may be possible.

Properties of Semiconductors

The class of substances known as semiconductors includes carbon (in the diamond state), silicon and germanium. Carbon atomic number 6, silicon 14, and germanium 32 have the common characteristic that each has four electrons in its outer or valence shell.

Germanium and silicon are the materials commonly used in transistors and crystal diodes available at the present time. Other semiconductor materials such as copper oxide also are used in rectifiers. In the solid state, purified germanium and silicon usually are in the polycrystalline form. They may be prepared in single-crystal form by several processes which give a crystal structure suitable for use in transistors. In a single crystal, the atoms arrange themselves in a regular pattern or lattice structure. The lattice of germanium and silicon is a cubic arrangement in which each atom is surrounded by four neighboring atoms all making equal angles with each other. For purposes of discussion, this three-dimensional array may be arranged symbolically in a two-dimensional form as shown in Figure 1. Here the four valence electrons of each atom form electron-pair bonds (covalent bonds) with four neighbors as indicated by the dotted lines. These covalent bonds are stable and restrict the motion of the

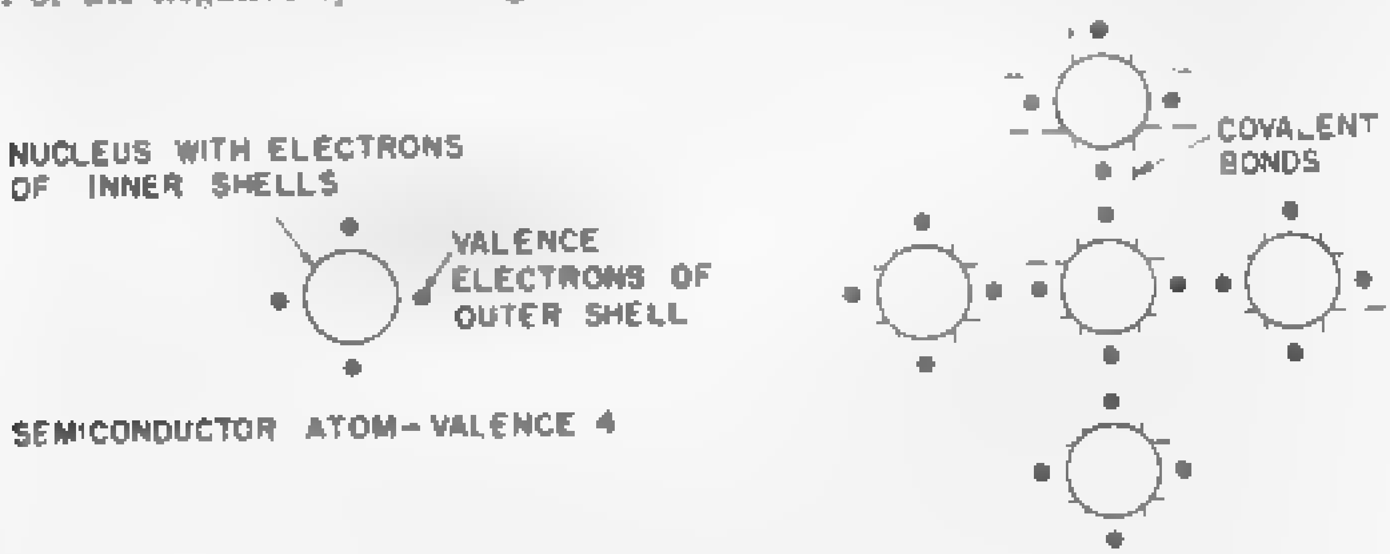


Figure 1. Crystal structure of perfect semiconductor

valence electrons to their individual bonds so that there are no free electrons to move from point to point in the crystal. In the absence of free electrons to carry current, a semiconductor would be a good insulator.

In germanium the binding energy is less than for silicon and at room temperatures thermal agitation is capable of imparting sufficient energy to the valence electrons so that a certain number succeed in escaping from their bonds. Likewise when light falls on the crystal, a quantum of energy may be delivered to one of the covalent bonds. Provided the energy is great enough, an electron will be ejected from the bond and is free to wander in the crystal. The empty space in the covalent bond left behind by the ejected electron is called a "hole." The generation of electron-hole pairs by incident light is the basic principle of operation of phototransistors and photodiodes. The crystal lattice then is as shown in Figure 2, where an electron-hole pair has been ejected from a covalent bond by thermal or light energy. Once generated, an electron-hole pair will remain in the crystal for a finite lifetime before recombining. The generation and recombining is a continuing process. In germanium the lifetime of an electron-hole pair is about 10^{-4} second. The process is one which reaches equilibrium very

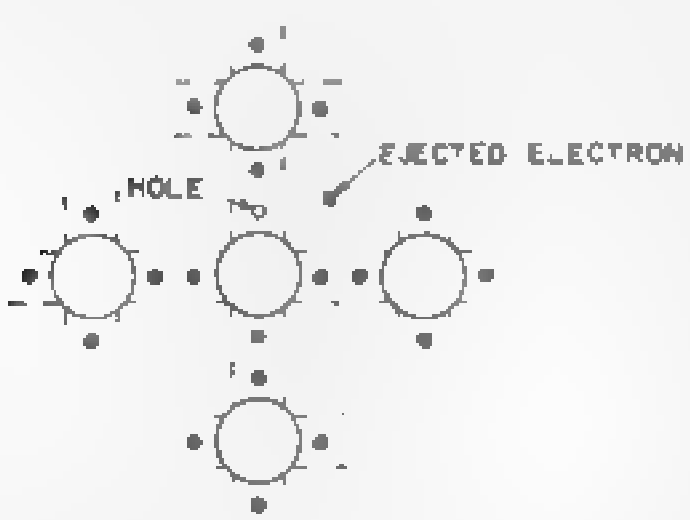


Figure 2. Crystal structure of intrinsic semiconductor

rapidly but as the concentration of free electrons increases, a point is quickly reached where the rate at which they are formed just equals the rate at which they are captured by ionized atoms.

There is a marked difference, however, in their ionizing process and that which takes place in a metallic conductor. In the metallic conductor the energy level of the free electron differs very little from the energy level of the valence electron. Consequently only a slight increase in the energy state of the electron is sufficient to eject it from the atom. In germanium the free electron is at a considerably higher potential energy level than the valence electron and this energy must be imparted to it from some external source in order that it acquire escape velocity. Similarly the "capture" of a free electron by an ionized atom must be accompanied by a release of energy (in the form of radiation) equal to that initially acquired. In accordance with accepted theories, these energy exchanges can occur only in certain discrete amounts. An electron which does not acquire the minimum energy necessary for escape does not escape partially. It either escapes completely or not at all. Without inquiring too rigorously into the actual nature or mechanics of ionization, we may infer in general that the effect of this energy difference or energy gap is to isolate the free electrons and the valence electrons, the two being separated by an energy gap through which they can pass only under certain restricted conditions. The two energy states are sometimes referred to as energy bands. That corresponding to the energy state of the free electron is known as the conduction band and the other as the valence band (or valence-bond band). The electron in the conduction band is far removed from the electron in the valence band; in fact, in atomic units of measure the conduction band is at an infinite distance from the valence band.

It may now be seen that in a substance having an atomic structure such as germanium, it is possible for an atom to lose one of its valence electrons without immediately acquiring another electron to fill the vacancy. The atom thus deprived of one of its valence electrons exhibits a unit positive charge whose value is equal

to the negative charge of the electron. This structural defect has characteristically been described as a "hole." Because of the large difference in energy levels the hole is much more likely to be occupied by an electron from the valence band of an adjacent atom than by an electron from the conduction band. When this occurs, however, it results in another hole being formed in the adjacent atom and as this hole is also more likely to be occupied by another valence electron, it appears to migrate from atom to atom just as if it were a positively charged electron. It should be noted, however, that this apparent motion of the hole takes place within the valence band.

It has been well established experimentally that such hole formation and hole migration actually occurs in germanium and other semiconductors and that the hole is further capable of transporting electric charge in a manner similar to that of a free electron. The only essential difference is that the charge is positive and the path of motion is within the valence band. The hole is effectively a positive mobile carrier.

While the period of existence (lifetime) of a hole may not be long as measured in ordinary units of time, statistically its existence is indefinite since, under conditions of thermal equilibrium, for every hole that ceases to exist as a result of capturing a free electron another hole is thermally created elsewhere in the material. Thus electron-hole pairs are continuously being formed by thermal agitation, the rate of creation being exactly equal to the rate of annihilation under equilibrium conditions. This maintains a constant concentration of free electrons and holes, both of which are capable of providing conduction.

It is evident that the presence of equal electron-hole pairs in a semiconductor would have no practical significance if there were no way of independently controlling their relative concentration. The development of the transistor was directly dependent upon the fact that methods were found by which it became possible to produce either type of carrier independently in the semiconductor material.

Controlled-Impurities Method

While there are now many techniques by which the desired type of carrier may be produced, the general principles may perhaps be best illustrated by describing the method which we will call the controlled-impurities technique. This method consists of adding a minute quantity of a certain type of impurity (impurity in the sense that a foreign element is added). One type of impurity produces a preponderance of negative carriers (electrons) and another a preponderance of positive carriers (holes).

If the semiconductor to be processed is germanium, for example, the first step is to purify the commercial product to the almost-inconceivable degree where there is only one impurity atom in each billion or more germanium atoms. This may be done by a method of progressively melting the germanium in a manner which will sweep the impurities towards one end. Conductivity tests indicate when the desired degree of purity has been attained.

Germanium having N-type conductivity (preponderance of negative carriers) is obtained by the addition of a small quantity (one part in 100 million) of either arsenic or antimony to the pure germanium. Similarly, by the addition of an equally small quantity of boron or gallium, P-type (positive carrier) germanium is obtained. By the addition of these so-called impurities to a melt of germanium, rate-grown crystals of N-type or P-type germanium may be produced by slowly withdrawing a seed crystal from the melt.

An NPN junction transistor is one having a minute portion of P-type material sandwiched between N-type material. The conductivity type may be changed from one to the other by the addition of the proper quantity of the desired impurity. The effect of adding one type of impurity to a melt already containing the other type merely cancels the original impurity. The

type of conductivity obtained is dependent only on whichever type of impurity predominates. Thus to produce an NPN transistor the mixture is first doped with, say, arsenic. After withdrawing a portion of N-type crystal, boron may be added to change the melt to P-type material for a short period after which arsenic is again added to produce the final N-type material. By the same method PNP crystals also may be grown.

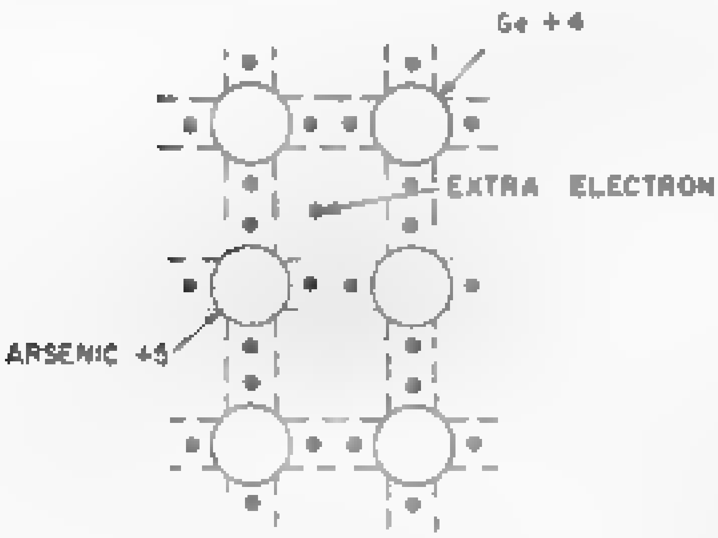


Figure 3. Crystal structure of N-type germanium

Arsenic and antimony are known as "donors." They have five electrons in their valence shell and when combined with germanium each atom of arsenic (or antimony) is capable of replacing a germanium atom in the crystal structure. Since only four of the valence electrons are needed to complete the crystal bonds the remaining electron becomes available as a "free" electron. In Figure 3 is shown the crystal structure resulting from the addition of an arsenic atom to replace a germanium atom in the crystal lattice to produce an N-type material.

While the arsenic (or antimony) atom has a positive charge normally sufficient to hold its five electrons, the binding force on the electron which fails to enter the crystal bond is so slight that it is easily dislodged by thermal agitation. It should be noted, however, that while a negative carrier is furnished by each donor atom the space charge of the crystal is not altered. The negative charge on each of the added free electrons is just balanced by the residual positive charge on each of the donor atoms held immobile in the crystal structure.

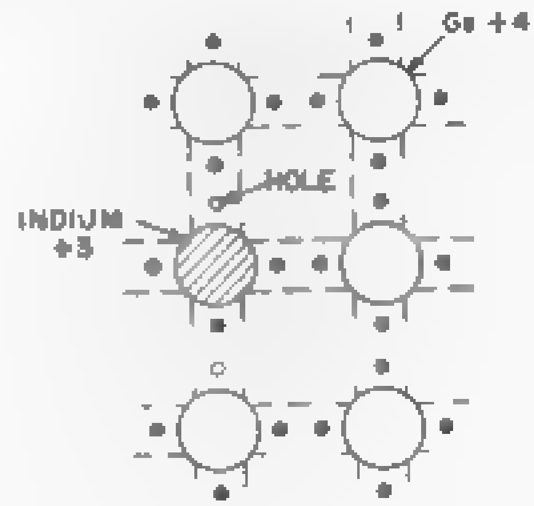


Figure 4. Crystal structure of P-type germanium

Boron and indium are known as acceptor impurities because they have only three electrons in their valence shells. While they enter the crystal structure in the same manner as the donor impurities, their three electrons as shown in Figure 4 are not sufficient to complete the crystal bond with the result that a hole is created by each such atom. While the boron (or indium) atom has a positive charge normally sufficient to hold its three electrons, when it is imbedded in the crystal structure it is not capable of preventing a fourth electron from occupying the hole. The hole therefore migrates through the crystal structure thus becoming a positive carrier. It should be noted, however, that while the boron atom has now become a negative ion (it has acquired one additional electron whose charge it cannot cancel) there is, somewhere within the material, a migratory hole whose positive charge just cancels the negative charge of the boron ion thus maintaining the space charge at its normal zero value.

In Figure 5 is illustrated a block of N-type and a block of P-type material. We may imagine that in some unspecified manner we are able to "see" the crystal

structure and the negative and positive carriers drifting about. In the N-type

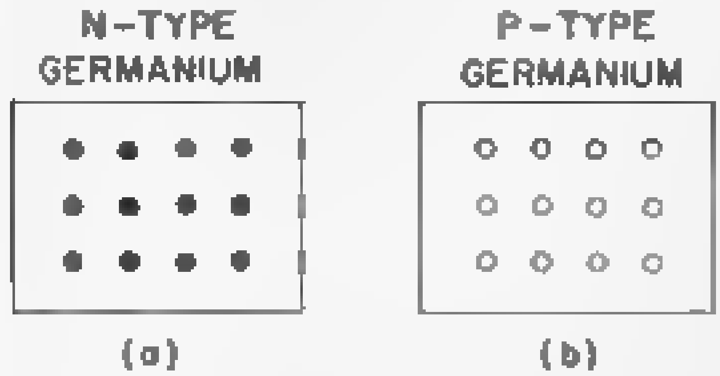


Figure 5. Separate blocks of N-type and P-type material

material we see innumerable electrons and in the P-type material an equally large number of holes. The electrons are those which have escaped from the donor atoms and are now in the conduction band, the holes are those which have escaped from the acceptor atoms and are now moving about in the valence band. Scattered throughout the N-type crystal there are also the immobile positively-charged ions of the donor atoms, and in the P-type crystal the immobile negatively-charged ions of the acceptor atoms. These neutralize the charges of the mobile carriers so that there is no space charge in either crystal. Since the only forces acting are those within the crystal, both carriers distribute themselves uniformly, each trying to get as far away from the other as possible.

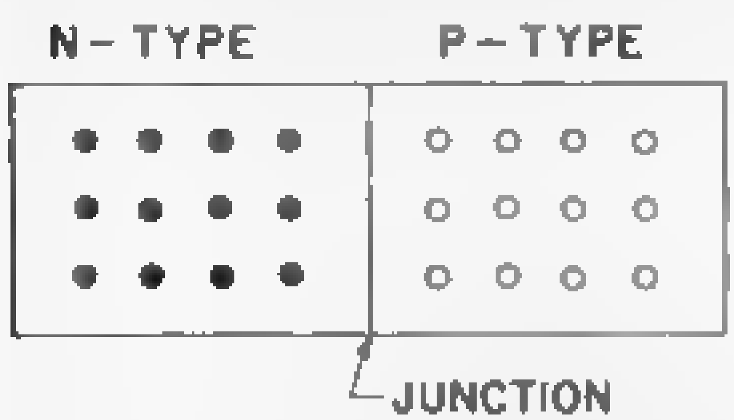


Figure 6. N-type and P-type material in contact

Crystal Junctions

Let us now imagine that the two blocks of material are placed in contact with each other as indicated in Figure 6. To obtain the type of contact we wish to form, however, it is necessary to join the two crystals so that their lattice structures are perfectly matched; that is, so that there are no imperfections at the surface of the juncture as would result if Figure 3 is joined to Figure 4. This, of course, cannot be done merely by joining the two mechanically. The desired type of contact may be obtained, however, by a method such as that previously described of "growing" the two blocks from a melt which is changed from N-type to P-type as the crystal is withdrawn.

The two blocks now form a PN junction. There are no imperfections at the boundary face or junction of the two materials, they blend right into each other to form a single crystal. The electrons on one side of the junction and the holes on the other side are now in such intimate proximity that new forces are brought into play. How they respond to these forces is illustrated somewhat crudely in Figure 7. We see that some of the electrons from the N-type material have drifted into the P-type material and some of the holes have drifted into the N-type material. This is evidently what we might expect since there is a mutual force of attraction between the positive and negative charges. The only question is, how far will this intermingling of carriers progress? Will they eventually be equally and uniformly distributed throughout the entire crystal? The answer to the last question is "no." To answer the first it is necessary to examine the forces acting a little more closely

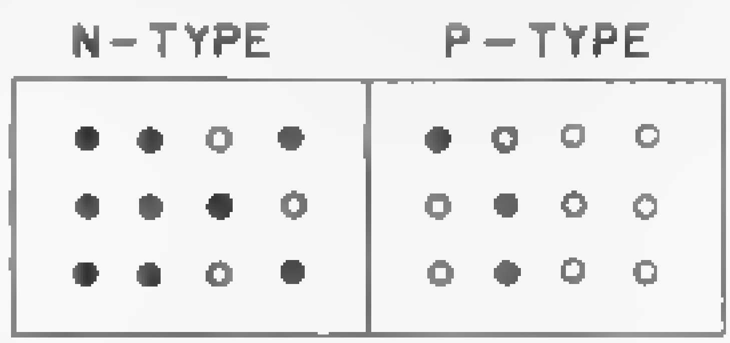


Figure 7. Carrier distribution in PN junction

To begin with, let us consider only the effect of electrons drifting across the junction into the P-type territory. It is evident that each electron that leaves the N-type material removes a part of the negative charge which previously cancelled the positive ion charge. Thus, as the electrons migrate across the border a positive space charge builds up in the N-type material. It does not build up uniformly, however, as may be seen if we imagine the blocks to be so long that the electrons at the far left feel almost no urge to migrate towards the junction. Since the electrons are moving towards the junction their density will be somewhat reduced at the left end of the N-type material and increased in the vicinity of the junction. Thus at the left the negative charge of the electron no longer quite cancels the positive charge of the ions, while progressively in the direction of junction the negative charge becomes larger than the positive, with the result that an appreciable negative space charge builds up in the vicinity of the junction. The charge build-up is actually an exponential function of the distance from the junction somewhat as indicated in Figure 8.

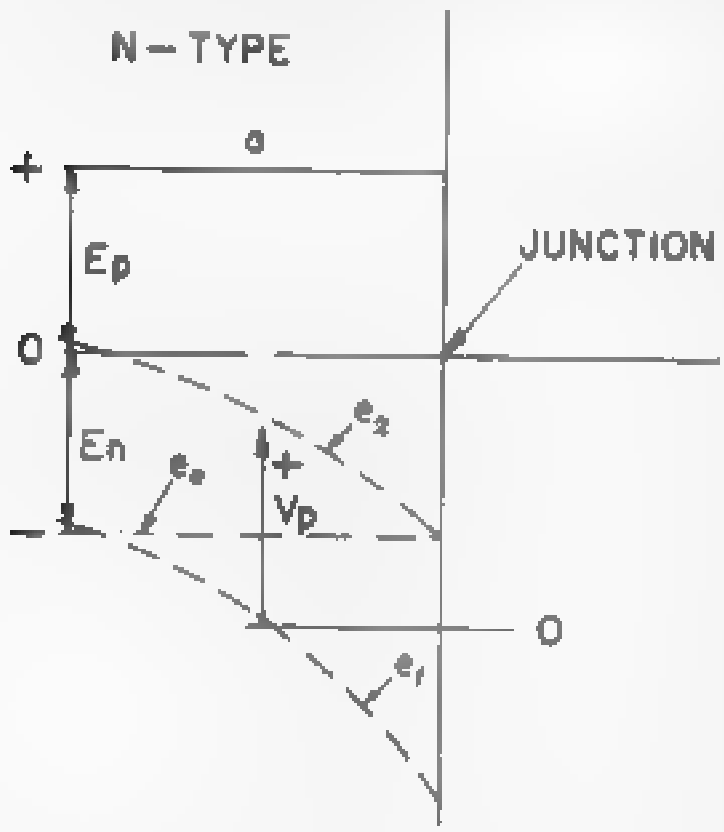


Figure 8. Potential barrier for semiconductor junction

The line e_0 represents the distribution of electron charge prior to migration of electrons into the P-type region. As the electrons drift towards, and across the junction, their density in the vicinity of the junction increases as indicated by the line e_1. This negative charge is reduced by the effect of the constant ionic positive charge indicated by line a. Before migration occurred the charge was completely cancelled but there is now a residue as indicated by line e_2. Its magnitude is the difference between a and e_1. With respect to the junction as the reference this results in an effective positive potential V_P as shown. This potential rises sharply at the junction and increases less rapidly at points farther removed. Its effect is to prevent further drift of electrons into the P-type region. It acts as a steep hill which the electrons must climb in order to cross into the P-type territory.

It may be difficult to visualize the downward sloping line e_2 as a "hill" but it must be remembered that since the electron carries a negative charge its motion into a more negative region requires expenditure of energy. To the electron, therefore, the line e_2 presents a voltage barrier, an energy "hill" which the electron must climb in order to move into the P-type region. The hill becomes higher as more electrons cross over until finally it reaches a level which effectively blocks further migration of electrons. In establishing this equilibrium condition there is a momentary flow of current but this rapidly diminishes and becomes zero. Although there may still be considerable activity statistically the electrons are now at rest.

In the same manner there is a migration of holes from the P-type material across the junction and into the N-type material. This also builds up a potential hill or barrier which quickly stops further migration. Thus both types of carriers encounter a potential barrier whose height is just that required to establish equilibrium.

Convenient Reference Terms

Expressions such as "statistically constant" or "statistically at rest" are useful

terms when dealing with electron or hole behavior. They refer to the average condition or state without regard for individual deviations from their state Other useful terms often employed in references to positive and negative carriers are "average life," "life expectancy," "population density," "birth rate," and "death rate." When so employed these terms have the same connotation as when used to describe biological events. Thus electrons and holes which lose their identities as carriers may correctly be said to have ceased to exist

It might be believed at first thought that all electrons which migrate into the hole-rich P-type material and all holes migrating into the electron-rich N-type material would instantly combine with the majority carrier and hence cease to exist. While their death rate no doubt increases they still retain a finite life expectancy. This is because of the relatively large energy gap between the electrons in the conduction band and the holes in the valence band Under suitable conditions, therefore, both positive and negative carrier may be present simultaneously in the same material Thermally created electron-hole pairs maintain the population of the two carriers at a constant level under equilibrium conditions.

If an external potential is applied across the PN junction with the negative side to the N-type end and the positive to the P-type, as shown in Figure 9, the immediate effect is to reduce or lower the potential barrier by an amount proportional to the applied potential E It is evident that the application of an external negative potential to the N-type material and a corresponding positive to the P-type material (with respect to the junction as reference) will lower the barrier potential since it acts to increase the negative space charge in the N-type material and the positive space charge in the P-type material. Since the condition prior to the application of the external potential was one of equilibrium, additional migration of electrons into the P-type material and holes into the N-type material will now occur in an attempt to restore the equilibrium condition. It should further be noted that current will flow under this condition in response to a voltage E A potential applied in this direction produces current in the direction of "easy flow" or, as more commonly known, in the "forward" direction It will be evident that the PN junction is a bilateral conductor; that is, a device having rectifying properties.

The rectifying properties become apparent if the potential E is reversed so that the positive is applied to the N-type end and the negative to the P-type. The connections are now as illustrated in Figure 10. With the PN junction connected in this manner the potential E attempts to withdraw electrons from the N-type region and inject electrons into the P-type region. The immediate effect of this will be to attract electrons away from the junction in the N-type material and holes

Figure 9 PN junction connection for "forward" flow

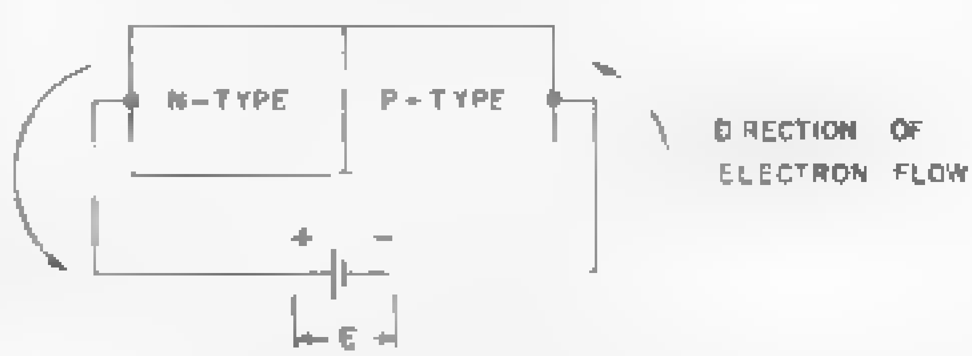


Figure 10. PN junction connection for "reverse" flow

in the P-type material. The resultant depletion of carriers near the junction will in effect cause this region to become a good insulator so that the potential E which was able to produce a relatively large current flow when poled as in Figure 9 will now be able to produce hardly any measurable current (a few microamperes perhaps) Thus if the steady potential E were replaced by an alternating potential, say that obtained from a transformer connected to a 60-cycle supply, current would flow during the half-cycle interval when the potential was that of Figure 9 but practically no current would flow during the other half-cycle interval. The PN junction would then be acting as a rectifier, its rectifying properties being obtained at the junction between the two types of material. In order that it function properly, the connections made at the end points to which the external potential is connected should be as completely unidirectional or nonrectifying as possible and have low contact resistance. Various bonding techniques have been developed for obtaining lead-out connections having these properties.

The PNP Junction Transistor

We have in the PN junction rectifier (or diode, as it is known) the basic building block of the junction transistor. If we could fit two of them together as indicated in Figure 11 it would become a PNP transistor. This "fitting together," however, would have to be done in the same manner as was done when joining the P and N sections to form the PN junction. It should be noted that the two N-type sections are the ones to be joined. Should we attempt to do this it would soon be found that it would be impossible to produce the proper junction by mechanically joining the two faces. The result would simply be two diodes pointed in two directions. For a proper junction of the two materials it would be necessary to fit the lattice structure of one to that of the other so they became one and the same crystal. A practical way to accomplish this would be to "grow" the crystal as previously described. A properly grown PNP crystal suitable as a transistor would appear (schematically at least, although not physically) as is shown in Figure 12.

It should be noted that only a small slice of the N-type material has been retained. As in the case of the PN junction the wires shown connected to the three regions are bonded to the material. They have no other function than that of providing entry and exit points for electrons flowing into or out of the crystal. The three regions are labeled "emitter," "base" and "collector."

Suppose we next connect the transistor to some external d-c potential as shown in Figure 13. It should be noted that the 0.2 volt applied to the emitter produces a current of one milliampere in the "forward" direction. The direction of current flow as indicated by the arrows is that of electrons, a direction opposite to its conventionally assumed one. Within the body of

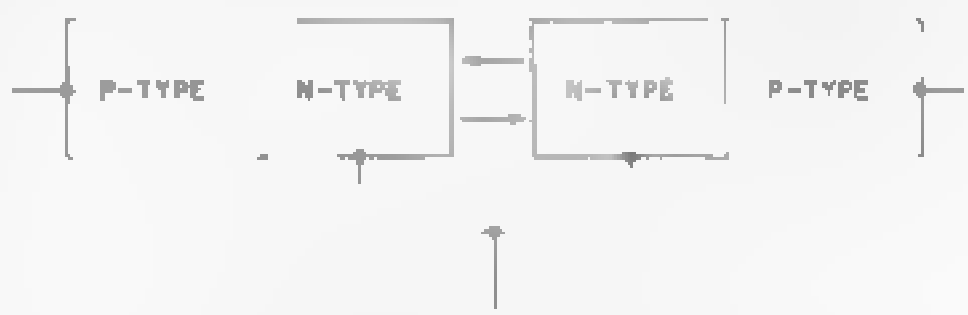


Figure 11. Basic building blocks for PNP transistor

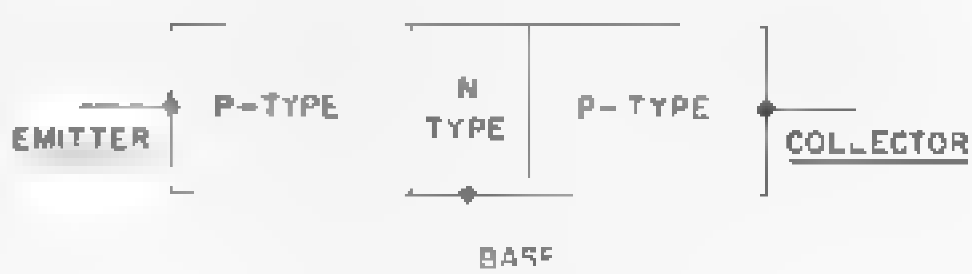


Figure 12. PNP junction transistor

the transistor current flows in both directions simultaneously, hole current in the conventional direction and electron current in the opposite.

The 1-milliampere emitter current is produced by the relatively small biasing potential of 0.2 volt. Since the emitter is P-type material, the current within the emitter will consist largely of hole current, holes moving in the valence band from left to right. On arriving at the junction barrier the holes migrate into the N-type base material. This is the direction of "easy" flow and only a small voltage is necessary to support the relatively large current flowing in the emitter.

The holes which enter the base region from the emitter tend to diffuse across the base material in the direction of the collector junction. The potential applied to the collector is negative hence the diffusion process is aided by the electrostatic field produced by this potential. If no potential were applied to the collector the holes would merely migrate in the direction of the base connection where, through combination with electrons entering the base, they would produce a base current equal to the emitter current. In the presence of the negative collector voltage, however, and because of the physical dimensions of the base region, the majority of the holes which enter the base arrive at the collector junction before they are annihilated through combination with electrons. The result is that a current of 0.95 milliampere flows in the collector circuit as the holes migrate across the junction into the collector

This process of forming a PNP transistor junction can be reversed to produce an NPN junction. In this case, a small P-section is sandwiched between two N-sections so that the symmetrical lattice structure is maintained at the junctions. Likewise, the battery potentials and currents are reversed in polarity

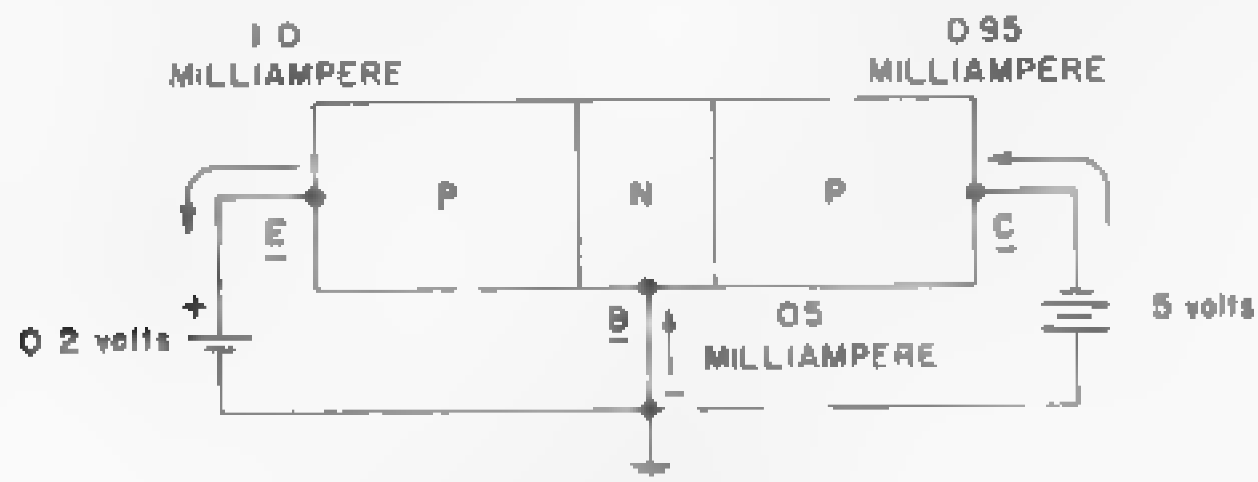
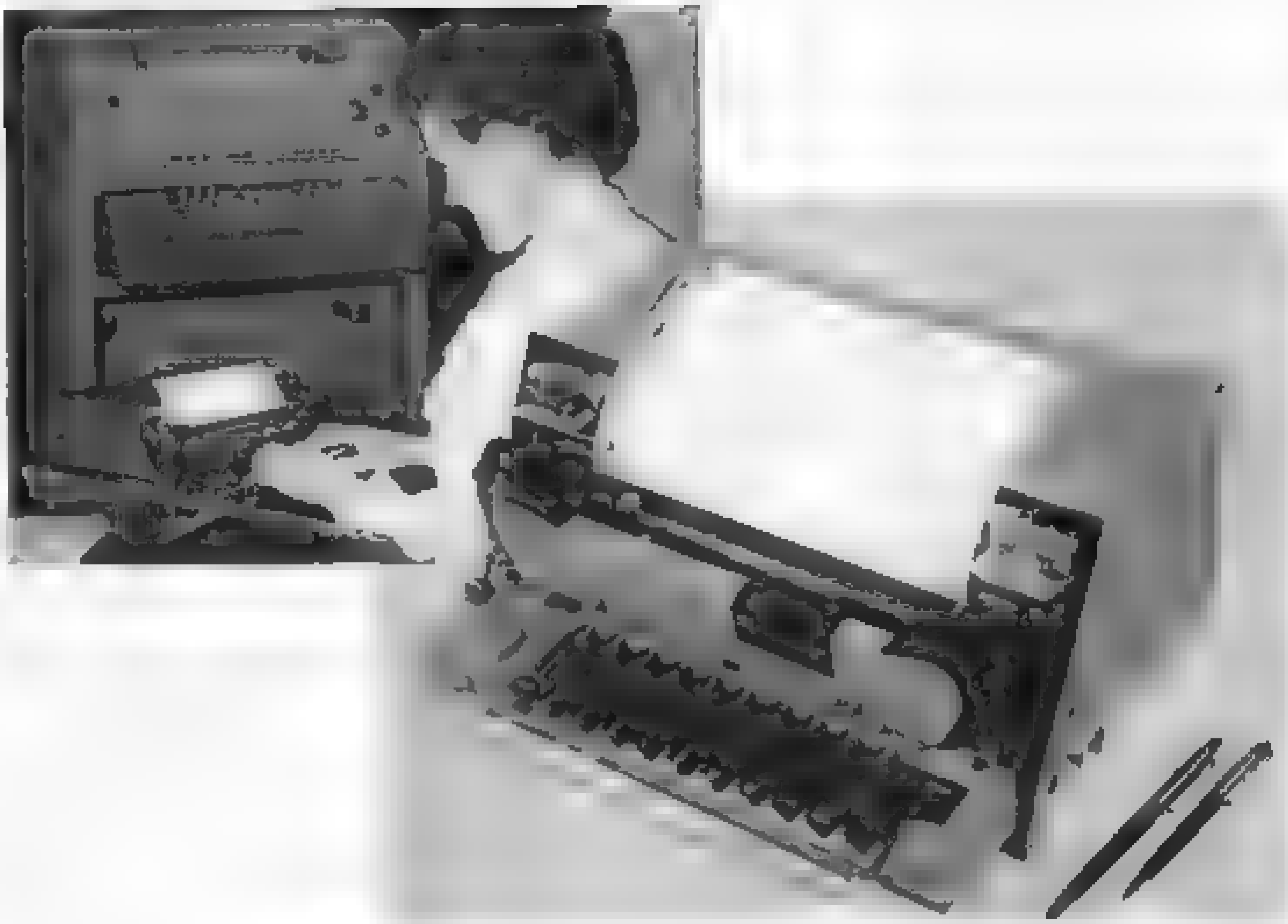


Figure 13. Transistor biasing currents

Basic aspects of transistor theory have been presented in simplified form primarily with respect to PNP junctions. Transistors constructed on PNP and NPN principles correspond in operating features to the electron tube triode. These basic concepts can be extended, however, to include other forms of semiconductor devices such as point contact and tetrode transistors and phototransistors. In addition still other mechanisms and semiconductor materials which are being studied may in the near future present a challenge to engineers and designers. Relatively few types of semiconductor devices have been reduced to commercial products, nevertheless the impact of these devices already is manifesting itself in the application of unique features for communication equipment and practices.

It is with sincere regret that TECHNICAL REVIEW records the recent passing of **Oscar E. Pierson** who had been associated with Western Union in various capacities, with unremitting application and outstanding accomplishment, since 1917. He started in the Traffic Department in Chicago and had become Division Traffic Inspector when, in 1930, he was transferred to the staff of the Engineer of Automatics in New York. Among his major assignments was the development of the Varioplex system, in which he took a leading part for some eight years; he was in large measure responsible for its successful application to telegraphy. In 1944, Mr Pierson was assigned to the Water Mill Laboratories of the Development and Research Department, where for several years he worked on the development of radar flight trainer equipment for the U. S. Navy. After completion of that project, he engaged in the development of a power supply for use in microwave experiments, development of frequency standards for ocean cable circuits, and design of electronic devices involving the use of transistors. Early in 1956 he returned to New York to work with the Automation Engineer; his sudden demise cut short a brilliant career in this field



Miniaturized Teleprinter Demonstrated

SHOWN ABOVE is a model of a new miniaturized teleprinter mentioned by Western Union's President W P Marshall and demonstrated at the annual meeting of share owners. The much larger type 28 teleprinter is in the background

"In addition to our large and growing requirements for Desk-Fax equipment to provide direct connections for our customers," said Mr Marshall "there is continuing need for teleprinter machines. Teleprinter equipment can be operated automatically at high-speed, it provides multiple copies and, most importantly, it can be used to produce the punched tape required for data processing or office automation purposes

"While the teleprinter thus fills a variety of important needs, particularly for companies which have both a large volume of telegraph business and data processing requirements, the heavy cost of printers, running as high as $1,700 each has been a substantial deterrent to their more widespread use. Nevertheless, we have nearly 23,000 teleprinter machines in customers' offices, and many thousands more in our own operating rooms

"In the light of what I have just said, you will understand our interest in the recent development by the Teleprinter Corporation, a relatively new concern located in New Jersey, of a miniaturized teleprinter machine which will take no more space than a portable typewriter The military, like ourselves, have long been keenly aware of the advantages inherent in such a development, and are currently negotiating with the Teleprinter Corporation You will be particularly interested in knowing that Western Union, in addition to working closely with the Teleprinter Corporation's people in testing and pre-production engineering of the equipment, has an option to buy a substantial part of the stock of this new company

It is understood that other makers of printing telegraph apparatus have been working to develop similar small machines to meet both military and commercial requirements

E. L. NEWELL, Project Engineer, Radio-Wire Transmission

Loading Coils for Ocean Cables

Before it was decided that submerged repeater-amplifiers offered the most practical means of increasing the message capacity of Western Union's nonloaded ocean cables, considerable work had been done in 1946-47 on development of coils for "lump loading" the older transatlantic cables. Although submerged repeaters were used successfully instead of lump-loading coils, it was recognized that the latter might well be employed to good advantage in the repair of the Telegraph Company's newer continuously loaded cables.

A suitable coil and techniques for its manufacture and use were developed subsequently by Western Union engineers. To date, 30 miles of lump-loaded repair cable has proved to be eminently satisfactory in regular service at a depth of 2000 fathoms for over a year. The saving in the cost of cable is estimated at more than $1000 per nautical mile.

THE WESTERN UNION cable system includes four continuously-loaded ocean cables: The Hammel-Horta cable (1HO) laid in 1924, the Hammel-Bay Roberts and Bay Roberts-Penzance cables (2HM-BR and 4PZ) laid in 1926, and the Bay Roberts-Horta cable (2HO) laid in 1928. No two cables are alike in the amount of loading or in capacitance and conductor resistance per mile.

Loaded Cable Repairs

Normally enough cable remains after the initial laying to provide adequate stock for repairs. Sufficient heavily-armored loaded cable of each type is in storage at the cable depots for all anticipated repairs in the shore ends of the loaded cables. The stock of loaded cable suitable for deep-sea repairs, however, was almost entirely depleted in repairing extensive damages to the cables suffered in the November 1929 submarine earthquake off the North American continental shelf. Since then, repairs in deep-sea sections of the loaded cables have been made with nonloaded cable.

Aside from the earthquake incident, there have been only four interruptions in the deep-sea sections of the loaded cables, two in 1951 and two in 1956, with a replacement of a total of nearly 50 miles of cable. A gradual increase in the number and extent of the repair requirements may be expected because of the accumulation of aging effects.

In the deep-sea sections of the cable, that is, at depths greater than 1000 fathoms (6000 feet), each cable repair usually adds at least five miles of nonloaded cable. This added length is twice the depth of the water plus the amount of cable that may have to be picked up before a fault is located. Occasionally up to 30 or more miles of cable may have to be replaced because of mechanical damage or deterioration from age. Repairs in shallow water near shore usually involve much less than five miles of cable.

Nonloaded stock repair cable can be used for the repair of loaded cables but only at the expense of signal deterioration. For every five miles of nonloaded cable inserted in the loaded cable, which increases the total cable length by that amount, the received signal amplitude is reduced by 4 or 5 percent as compared to a reduction of 2 percent when the proper type loaded cable is used. For every five miles of nonloaded cable which replaces loaded cable without increasing the total cable length, the received signal is reduced by 2 to 3 percent. In addition, inserted lengths of nonloaded cable of the order of 5 to 30 miles may result in multiple reflections at the ends of the nonloaded section with a consequent loss of received signal as high as 50 percent. An instance of a 50-percent signal reduction occurred when a 22-mile section of

A paper presented before the Summer General Meeting of the American Institute of Electrical Engineers in Montreal, Que., June 1957

nonloaded cable was inserted in the Bay Roberts-Penzance 1926 cable in order to reroute it around the trawler area on the Newfoundland fishing banks. Less than half of this loss can be attributed to the attenuation of the added nonloaded cable, the major part of the loss was due to the multiple reflections.

While it is undesirable from a transmission point of view to use nonloaded cable for loaded cable repairs, the cost economy is considerable. Nonloaded repair cable costs about $3,000 per nautical mile, continuously-loaded cable normally about $4 500. However, the present cost of the loaded cable would be considerably more because special machinery for forming, applying, and annealing the loading material would first need to be built. To this initial cost of the loaded repair cable must be added carrying charges on an adequate stock and the expense of storing it at the cable depot and on the cable ship.

Lump Loading

Nonloaded repair cable must be carried in stock in considerable amount for use in the older nonloaded cables. The idea immediately occurs that this same stock would be entirely adequate also for the repair of the loaded cables if suitable loading coils were inserted in the nonloaded repair cable to make it electrically equivalent to the continuously-loaded cable. Such lump loading has been widely used in telephone landlines and to some extent in submarine cables.

Loading coils were first used in a submarine cable in 1906 when Siemens and Halske in Germany laid a lump-loaded telephone cable 9.3 miles long across Lake Constance. Subsequently several lump-loaded telephone cables were laid across the English Channel and across the Irish Sea by the British Post Office. These were all short cables lying at depths nowhere greater than 150 fathoms.

Lump loading, while electrically very satisfactory, has been considered impractical for long submarine cables lying in deep water because of the difficulty of preventing water penetration at the great pressures encountered in deep water, and because the discontinuity in the cable at the point of insertion of the coil might weaken the cable mechanically and increase the hazards of laying. However, the many new materials now available have made lump loading more attractive. In fact, considerable work was done in 1946-47 on development of coils for lump loading Western Union's transatlantic nonloaded cables, but the project was abandoned in favor of the submerged repeaters. Loading coils still appeared to offer an economical means for the repair of the continuously-loaded cables, and the development was directed to that end

Design Considerations

The physical requirements for a deep-sea loading coil are severe. The coil must withstand hydrostatic pressures of three or four tons per square inch without water leakage or damage to the stress-sensitive high-permeability alloys which must be used as core material in the coil in order to obtain high electrical efficiency with small size. The coil should not be permanently affected by the great stresses, either longitudinal or bending, that may occur during the laying of the cable in deep water. Also the coil should not introduce into the cable any discontinuity which might interfere with the normal tightening of the spiral lay of the armor wires as the cable passes over the bow sheave, or with the release, or untwist, as the cable nears sea bottom. To do so might cause a serious kink in the cable. It is very desirable, too, that the loading coils require no special handling as the cable is being laid

Materials used in construction of the coils must not deteriorate with age, at least not more rapidly than the cable itself, and must be free of any undesirable chemical interactions either during construction or after laying. The most practical method of meeting these conditions appeared to be to make the loading coil an integral part of the cable with the armor wires extending, continuous and unbroken, over the coil. At the bulge created by the coil, additional wires would be interposed in the armor to provide

complete coverage. The coils could be spliced into the nonloaded stock repair cable as required and then be laid as part of the cable without special attention

Typical nonloaded cable used for repairs is one inch in diameter over-all. An enlargement to three inches at the point of insertion of the loading coil is about the maximum bulge that can safely pass through the cable ship gear during laying of the cable. More particularly, the diameter over the armor was limited to something less than 2.75 inches since that was the maximum that could be handled in the available armoring machines. Then, allowing space for armor wires, padding, and insulating jacket, the diameter of the loading coil itself could not exceed 1.5 inches. Assuming some sort of protective case, the diameter of the core and winding would be limited to about 1.25 inches. The length of the coil would depend on the amount of core material and winding required to give the desired inductance and resistance

The electrical characteristics of the loading coil should be such that, when inserted in nonloaded stock repair cable, it makes the repair cable equivalent to the continuously-loaded cable in impedance and not appreciably greater in attenuation. Calculations showed that coils inserted in the repair cable at 5-mile intervals should have an inductance of 0.3 henrys and a resistance of not more than 7 ohms, alternating plus direct current at 60 cycles per second and 1 to 20 milliamperes, in order to match the 4PZ loaded cable. The same coil inserted with 3-mile spacing would match the 2HM BR cable, and with 6.8-mile spacing the 1HO cable. These spacings would be quite adequate to avoid reflection losses which increase attenuation or affect wave shape; for all practical purposes these spacings would give the effect of a smooth (continuously-loaded) cable within the range of telegraph frequencies.

Figure 1 shows how the impedance and attenuation of the lump-loaded repair cable would vary with the spacing of 0.3-henry 7-ohm loading coils. Good impedance and attenuation matches can be obtained with the loading coils at 3, 5, and 6.8-mile spacing for the 2HM-BR, 4PZ and 1HO cables respectively. Figures 2, 3, and 4 indicate the degree of equivalence that would be obtained over the range of telegraph frequencies.

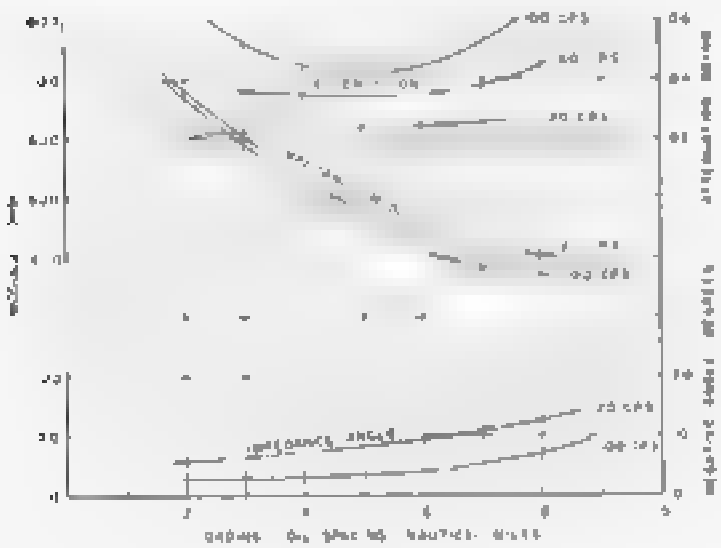


Figure 1. Characteristics of lump-loaded stock repair cable

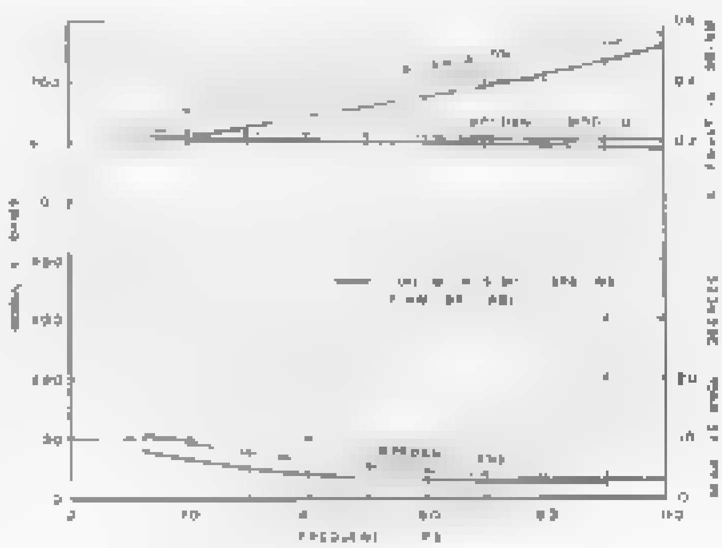


Figure 2. 3-mile spacing and 2HM-BR cable

In the case of the 2HM-BR cable, if 5-mile spacing is used instead of the indicated 3-mile spacing, the reflection loss due to impedance mismatch does not increase the attenuation enough to bring it above the normal attenuation of the loaded cable itself. In other words, the more economical 5-mile spacing can be used in this cable with no greater loss in transmission efficiency than would be occasioned by the use of the same length of continuously-loaded cable for the repair.

The most suitable coil spacing in the case of the taper-loaded 2HO cable depends on the location in the cable. The spacing would vary from about 3 or 4

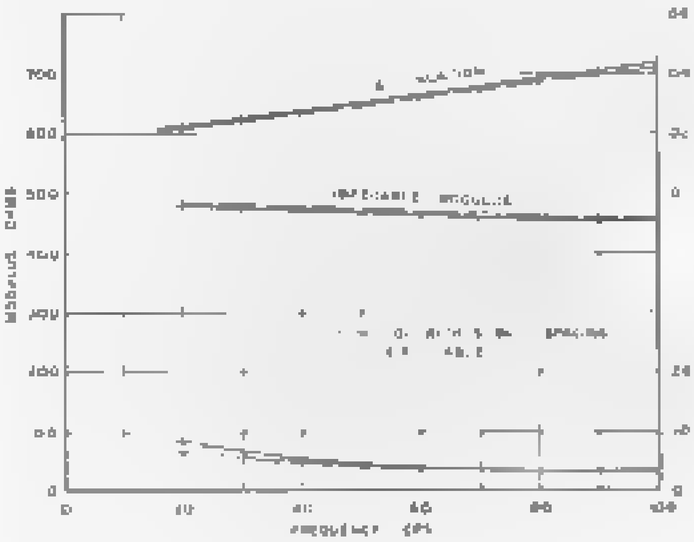


Figure 3. 5-mile spacing and 4PZ cable

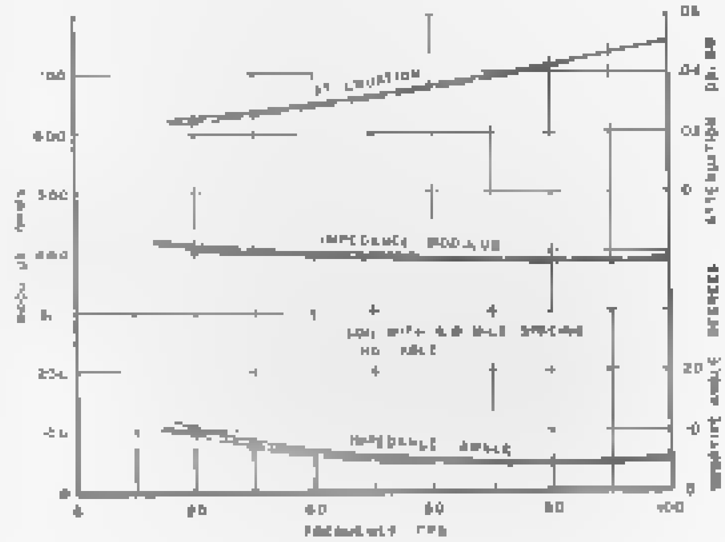


Figure 4. 6.8-mile spacing and 1HO cable

miles in the heavily-loaded center of the cable to 8 or 10 miles in the more lightly-loaded end sections.

The Loading Coil

Figures 5 and 6 show the loading coil—less jacket and armor—that was developed to meet the preceding conditions. The winding, with its laminated core of high permeability steel, is located midway in a stainless steel tube 1.5 inches in diameter by 6.25 inches long. Spiral pigtails connect the winding to the 4-inch-long cable conductor stubs which are anchored in insulating end plugs. Two insulating liners keep the winding and core centered during construction and keep the winding pigtails clear of the metal tube. The assembly is impregnated with a rubber-like compound.

To complete the coil, 45-foot-long sections of cable core are joined to the short stubs, and the coil is covered with an insulating jacket. Regular wire armor is then applied over the entire length with additional wires interposed at the bulge over the loading coil.

Construction Details

Some of the winding and core construction details may be seen in Figure 7. At the lower left is the winding form and the clamp which holds the winding in shape during its initial impregnation.

The core is made up of 0.007-inch-thick modified E-type laminations of annealed mu-metal or molybdenum permalloy. In building the core the laminations for one coil are first assembled in a jig (see top Figure 7) in eight 15/32-inch stacks and impregnated with a compound that firmly binds the laminations together. After removal from the jig, the gap faces of each stack are leveled on fine abrasive paper

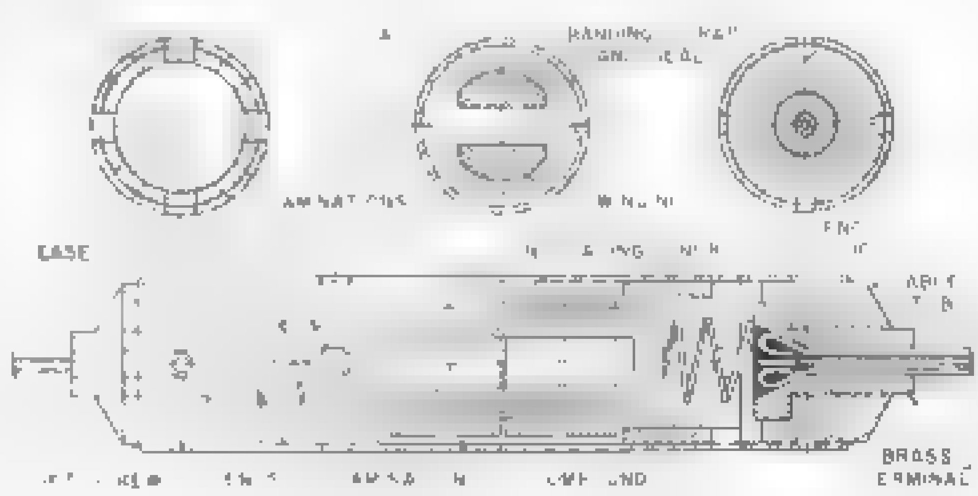


Figure 5. Sectional view of loading coil

This operation is rather critical since too little leveling results in a large change of inductance when the coil is subjected to sea-bottom pressure; too much leveling

produces burrs on the edges of the laminations with consequent increase in the a-c resistance of the coil

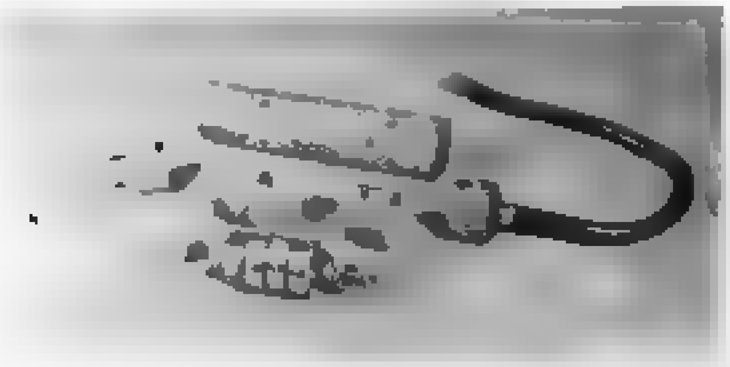


Photo R 9925

Figure 6. Loading coil components

The core stacks are assembled on the winding in pairs with 0.0007-inch paper gaps and held together with phosphor bronze straps under a tension of 75 pounds (lower right in Figure 7). A space of about 1/32 inch is maintained between the stack pairs to provide a cushioning layer of impregnating compound.

The core and winding are impregnated as a unit and then assembled in the metal tube with the liners holding them in place.

The impregnating compound is a thermosetting, polyester resin which is a thin liquid when its two components are first mixed but after curing for several hours at 250 degrees Fahrenheit assumes a consistency of rubbery gelatin. The function of the compound, in addition to holding together the laminations and the winding turns, is to float the core and winding inside the steel case and to transmit sea-bottom pressures uniformly to all parts of the core so that no bending stresses are set up in the laminations with consequent loss in the coil inductance and increase in the a-c resistance

To secure the desired uniform pressure distribution, there must be no voids in the impregnated unit. Voids may occur as a result of incomplete impregnation, shrinkage of 2.5 percent by volume during the curing process, and thermal shrinkage of about 4 percent between the 250-degree curing temperature and normal room temperature. A further thermal shrinkage of 1 percent occurs as the coil goes to sea-bottom temperature of about 34 degrees Fahrenheit

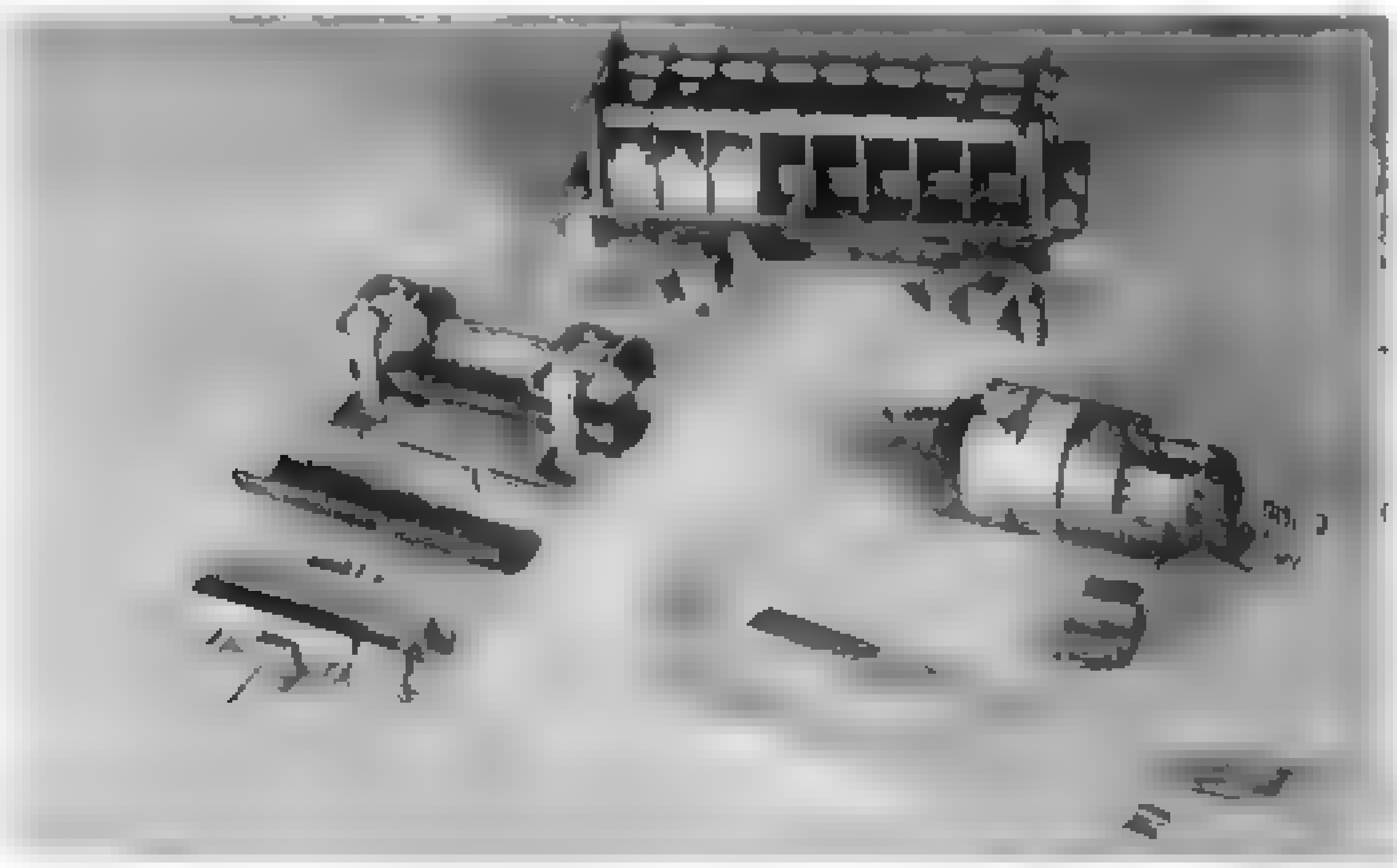


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Figure 7. Loading coil construction details

After soldering on the winding terminals, the end plugs with their cable stubs are put in the tube and the whole is given a final impregnation.

Initial voids are minimized by careful vacuum impregnation after first thoroughly dehydrating the coil components and the compound itself. Curing and

thermal shrinkages, except the last 1 percent at sea bottom, are taken up by forcing the end plugs about 1/16 inch further into the coil case after impregnation. The set screws holding the end plugs in place are not finally seated until after this operation. Sixteen 1/4-inch holes in the coil case facilitate the impregnation and later, under sea-bottom pressure, permit easy entry of enough of the jacket material to fill any small remaining voids without damage to the jacket.

After impregnation is completed, two 45-foot lengths of standard insulated cable core are electrically brazed to the short stubs in the end plugs. The jacket is built up with a tightly wrapped butyl-synthetic rubber tape which forms into a compact, elastic mass without any heat treatment. The jacket is 1/4 inch thick over the coil and extends several inches beyond the ends of the coil to make a watertight joint with the insulation on the long cable stub. At this point the coil is given a 24-hour pressure test in water at 7800 pounds per square inch to check the insulation and the effect of pressure on the inductance and a-c resistance.

Before armoring, the stub on each side of the coil is built up with burlap tape to provide a smooth taper extending to 20 feet each side of the coil. This is followed by a wrapping of jute over the entire length to provide a bedding for the armor. The armor consists of 24 galvanized steel wires, 0.095 inch in diameter, extending the full length over the coil and cable stubs. Over the coil are interposed 39 additional wires, 0.112 inch in diameter, which are terminated, 13 at a time, at approximately 4, 12, and 20 feet each side of the coil as required to cover the tapered section. Armor wire ends are held in place by whippings of 16-gauge steel wire. Finally, over all, is the standard serving of tarred hemp to provide some mechanical protection for the armor. The finished diameter over the loading coil is 2.85 inches and over the cable stubs about 1 inch.

The first lot of loading coils was armored on a machine which required that the added wires over the coil be laid on by hand. Later coils were armored on a new and completely automatic machine developed at the Newington, N. H., plant of the Simplex Wire and Cable Company to armor the repeaters installed in the recent transatlantic telephone cables.

Coil Characteristics

The inductance of the loading coil is set at 300 millihenrys, at 60 cps and 10 milliamperes, by adjustment of the gap in one of the four sections of the core. There is normally little or no change in inductance between atmospheric pressure and sea-bottom pressure provided the leveling of the gap faces has been done to the proper degree, and in the impregnation there have been left no appreciable voids in the vicinity of the core and winding. The a-c resistance is usually 20 to 25 percent greater at sea-bottom than at atmospheric pressure, but in most of the coils so far built it has been 15 to 25 percent less than the design value. The attenuation of the lump-loaded repair cable, as a result, will be somewhat less than indicated in Figures 1 to 4.

Figure 8 shows the variation of inductance and a-c resistance with current for a typical loading coil under 8000 pounds per square inch pressure. The a-c resistance of the loading coil is normally 1 to

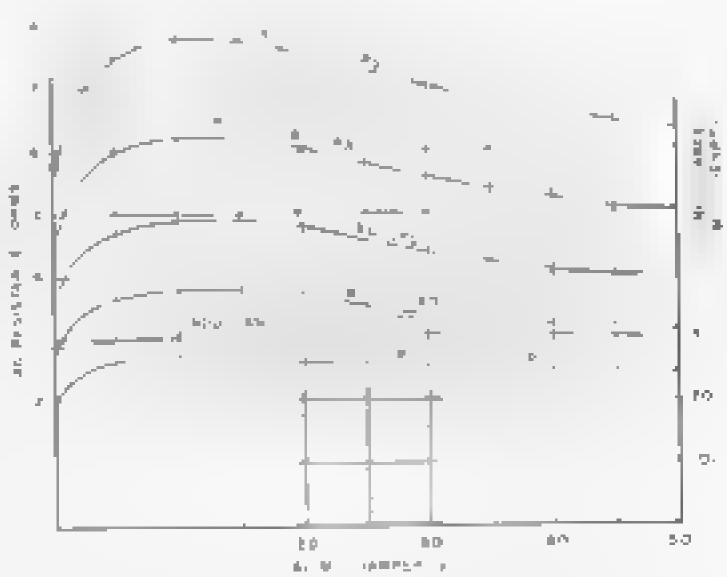

Figure 8. A-c characteristics of loading coil

2 ohms less than the 7-ohm design value, and for currents up to 10 or 15 milliamperes the increase in inductance and a-c resistance with current is slightly less in

the loading coil than in the loaded cables. Above 15 milliamperes the a-c resistance of the coil drops while that of the cables increases rapidly with current. The inductance of the cables also increases rapidly at the higher current, but the inductance of the loading coil is nearly constant. While the inductance and a-c resistance, particularly at the higher signal currents, do not have the same pattern of change in the loading coil and in the cables, the increase in attenuation due to the higher currents is less in a coil-loaded repair section than in the loaded cable itself. In any case, the Hammel-Horta cable is the only one in which the signal currents exceed 15 milliamperes in sections where the coils may be used. In this cable the currents are as high as 25 milliamperes in the Hammel end and 40 milliamperes in the Horta end.

Under normal operating conditions direct currents in the loaded cables due to earth potentials do not exceed 10 milliamperes and have very little effect on the inductance or a-c resistance of either the loading coils or the loaded cables. Direct currents up to 80 or 100 milliamperes may flow in a cable circuit when protective devices installed at the terminals are operated by excessive earth potentials. Such currents will not damage the loading coils.

To check the effect on the loading coil of stresses encountered in laying or picking up the cable in deep water, one completely armored loading coil with long cable stubs was tested by passing the coil several times over a 7-foot diameter drum while under a longitudinal tension of 16 000 pounds. There was no mechanical damage to the coil, and the electrical characteristics were not affected.

Loading Coils in Use

In April 1956, the Hammel-Bay Roberts loaded cable (2HM-BR) was interrupted 325 miles from Bay Roberts at a depth of 2000 fathoms. Because of the poor condition of the cable, probably from damage sustained in the 1929 earthquake, 23 miles of cable had to be replaced. The replacement was made with 30 miles of nonloaded stock repair cable, the extra 7 miles of repair cable being the normal added length required to effect a repair in deep water. Loading coils were inserted at 5-mile intervals beginning and ending 2.5 miles from the end of the repair section.

As previously stated, 5-mile spacing of the coils can be used in the 2HM BR cable, instead of 3-mile as indicated in Figure 2, without degrading transmission. However, in this case the 5-mile spacing was dictated by the fact that only six loading coils were available.

The six loading coils have been in service now for over a year without incident. No attenuation measurements have been made on the 2HM-BR cable since the repair but, as far as can be judged from the appearance of the operating signals, the insertion of the nonloaded cable and loading coils has not increased the attenuation or otherwise affected the signals. A comparison of signals is complicated by the fact that a partial fault of long standing was eliminated by the repair.

The six loading coils installed in the 2HM-BR cable plus six recently completed and stored at the cable depot in Halifax, Nova Scotia, were all constructed in the Western Union Laboratory at 60 Hudson Street with the exception of the jacketing and armoring which was done by the Simplex Wire and Cable Company. Arrangements are being made with a commercial supplier to manufacture a number of loading coils that will provide adequate stock for future probable loaded cable repairs.

The loading coils, complete with armor, cost about $2,000 each. Thus, for the repair of continuously-loaded cables, the use of nonloaded stock repair cable with inserted loading coils instead of continuously-loaded repair cable results in a saving of more than $1,000 per mile of repair cable used.

Acknowledgments

Many people, in their special fields, have made contributions to the loading

coil project. Especially mentioned should be G. A. Randall and P. H. Wells for their calculations to determine the required constants of the coil, R. C. Taylor for the design of the coil winding and core, and T. Rystedt who was responsible for many of the precision construction features of the coils. The method of jacketing and armoring and of anchoring the cable stubs in the end plugs was developed jointly with the Simplex Wire and Cable Company of Cambridge, Mass.

E. L. Newell was graduated from Union College with the degree of B.S. in E.E. in the class of 1918 and received the E.E. degree from the Graduate School of Columbia University in 1922, his studies having been interrupted by two years' service in the U. S. Navy. He joined the Transmission Research Division in 1922 where he has since been engaged mainly in the field of submarine cable transmission. His work has included supervision of the field work in connection with the duplexing of the Bay Roberts-Horta loaded cable, development of a 2-channel FM carrier system for short submarine cables, and more recently much of the mechanical design and construction of the submerged repeaters for nonloaded cables and of loading coils for the repair of loaded cables. He has also been active in the development of equipment for the elimination of radio interference originating in the telegraph system. Mr. Newell is a member of AIEE, Tau Beta Pi, and Sigma Xi.

Keying Loss in Telegraphy

An article entitled "A Review of Proposed Carrier Systems for Data Transmission" in the April Review elicited considerable comment. In response to one inquiry respecting the effect of varying time relations between carrier and keying, the author prepared a reply which may well be of interest to other readers.

It is probably easier to comprehend the general principles of keying loss in telegraphy if one thinks first of what happens in the AM situation. In FM, there is analogous effect though it is not quite so easy to visualize.

Let us consider first a carrier source, the frequency of which is subject to some minor drift perhaps, but is still adequately stable for telegraphy. In AM, it is alternately connected to the transmission path and disconnected in accordance with the pattern set up by the intelligence code. The code signals, which do the on-off keying, are ordinarily timed by a mechanism not geared to or synchronized with the carrier source. If the telegraph machine is keyboard operated, the timing of the on-off keying of the carrier is entirely random with respect to the carrier phase. Even if transmission is from a mechanical tape reader, the time relation between the carrier and the keying, if not random, is drifting. Further, the length of the intelligence bit bears no fixed relation to any integral number of carrier cycles.

The result of this situation is that the train of carrier cycles which represents a bit may begin and end in any position on the carrier wave. The carrier when turned on may be starting either a positive or a negative excursion at the instant it is connected to the circuit, or it may be at the positive or negative peak of its excursion, or have any intermediate value whatever. Similarly, it may be disconnected at the end of the bit at any phase position whatever. The fact that a narrow-band filter system intervenes the circuit from transmitting keyer to receiving detector does not alter the erratic timing of the detected intelligence bit. The filters with their slow rise and decay only integrate the carrier train into a more or less sinusoidal envelope shape.

Some very precise measurements have been made on the magnitude of this effect. All confirm the intuitive estimate that the intelligence signal bit length is undependable in the exact relation of the signal frequency to the carrier frequency. With a 100-cycle rate, 200 bits per second (bit length 5 milliseconds), on a 1000-cycle carrier, a threshold fortuitous signal loss of 10 percent of signal length is encountered. The total shortening of any particular bit attributable to this distortion then may be as much as 0.5 millisecond.

Intuition too tells us that this uncertainty of beginning and ending would be reduced by 50 percent were a full-wave rectifier employed in the place of the single-wave device common in the carrier telegraph terminal. Such is in fact the case as closely as the most carefully made measurements can determine. In certain carefully engineered carrier channels, where a low-frequency carrier must be used, full-wave detection has been employed to advantage.

In FM, there is a closely parallel phenomenon. The uncertainty of the timing of the intelligence bit with respect to the specific instantaneous phase of the carrier still exists. In this case, however, the usual discriminator and detector circuitry functions as a push-pull device. The measured "keying" distortion on Western Union's standard FM telegraph channel is proportional to half the ratio of intelligence frequency to the mid-channel carrier frequency. With the bit rate and carrier frequency as chosen for the previous example, the keying loss is 0.25 percent.

In the situation where the intelligence frequency is made first to modulate an intermediate high-carrier frequency, the keying loss is only that which attends the improved intelligence-carrier ratio thus

obtained. The transfer modulator which subsequently puts the modulated signals to a lower register for transmission over the line facility is a linear device. It reproduces the envelope faithfully and so introduces no additional timing uncertainty. Numerous experiments have been made by several investigators to prove this point. In one set of tests performed in Western Union laboratories, the low-frequency carrier location was actually made to approach closely the frequency of the modulation rate. One cannot quite make them coincide because of the difficulty of passing frequencies near zero through the equipment components.

"Keying loss," as the expression is generally used amongst telegraph engineers, has nothing whatever to do with the loss of sideband energy either at the frequencies representing the first-order sideband or those beyond. It is a phenomenon which will be present when the band through which the modulated signal is passed is infinite in width. It is a simple matter of the carrier being too "coarse grained" to permit adequate resolution of the bit image. Nor does nonlinearity of phase response enter into the basic concept. We have made no controlled experiments to determine if phase distortion affects the relative magnitude of the keying loss, probably because there has been no evidence of any such effect.

In general, symmetrical amplitude cutoff within the first-order sideband range and somewhat beyond results in "previous history" bit distortion which we call "characteristic distortion." In general again, asymmetrical pass-band attenuation shape results in some asymmetrical characteristic distortion which may or may not show up as bias. Asymmetrical characteristic distortion is that distressing and uncorrectable type which behaves differently on negative-to-positive transients than on positive-to-negative transients. Asymmetrical phase distortion produces a similar effect. The effect of all these things, however, is quite independent of keying loss and, so far as is known, does not alter the latter.

The principles here set forth are quite as applicable for high-speed data transmission as for commonly-used telegraph signaling.—F. B. Bramhall, Transmission Planning Engineer

H. F. KRANTZ, II, Project Engineer, Electronics Applications

A Combination Multiplex-Teleprinter Way-Station Circuit

The Telegraph Company's three Key West-Havana submarine cables, each about 100 nautical miles in length, are equipped at the terminals to permit operation of the physical circuits as 3-channel or 6-channel multiplex circuits and to provide a carrier system for two teleprinter or 50-cycle multiplex circuits. An interesting arrangement has been engineered to allow a way-station teleprinter circuit to be assigned over a multiplex channel on these cables.

UPPERMOST in the thoughts of almost everyone engaged in serving the public is the feeling that the most should be made of any single facility in order to gain the highest possible economy of operation. This is particularly true in the field of ocean cable telegraphy where the cost of a new facility is much higher than in other media and yet, as in other fields, the criterion is service; service for anyone who desires it, and service with maximum reliability.

In order to gain the advantage of having a channel of the Key West-Havana cable carrier facility[1] freed for additional purposes, Western Union's International Communications Department requested that a teleprinter way-station customer's circuit be shifted from one of these narrow-band carrier channels to an available multiplex channel. This customer had offices in Chicago, New York, West Palm Beach and Havana, all connected by means of narrow-band carrier channels as shown in Figure 1A. The proposal called for all drops to be connected by carrier to a "hub" in New York with the Havana leg brought in via one channel of a NY-HAV multiplex circuit as shown in Figure 1B. Ordinarily this would seem to be a routine routing reassignment; however, the multiplex leg to Havana presented some interesting problems which were met and overcome as described in this article.

Under normal idle conditions the multiplex sends "blanks" or spacing impulses from the transmitters of its individual channels, whereas an idle teleprinter circuit normally carries a marking signal. A spacing condition on the landline facilities is not the *normal* idle condition. In fact, it is a spacing time interval which initiates teleprinter way-station selector operation.

Figure 1. Circuit layout proposal

This then was the problem, make an ordinarily idle spacing multiplex channel recognize, transmit and decode the initial spacing interval of a way-station selection procedure.

Way-Station Operation

Briefly, the theory behind the teleprinter way-station operating procedure is as follows. A way-station customer is one who leases private service to a number of different remote locations or "drops." Each drop is assigned an office call designation which is determined by additional contacts on the code bars of the

printer within its console. This customer has exclusive use of the circuit facilities connecting the drops, and when none of the various offices has a message, the line stands idle with the printer motors turned off. This is characterized by a closed leg between the customer and the Western Union office and, in the usual case for landline operation, by marking frequency over the carrier facilities connecting the distant cities.

Should the office in Chicago, for the case in point, desire to query their West Palm Beach branch on some matter, a simple, set routine to cut that office in is followed. The operator in Chicago pushes a call button which opens the leg to the Western Union office, and in consequence spaces (opens) the entire network. This timed open permits the motors of all drops to start and the printers of all drops are ready for operation at the end of the predetermined five seconds. Chicago then types its own and the West Palm Peach office call letters causing these printers to be locked in. All other drops, not having been selected by call letters, automatically shut down except for a warning lamp which indicates that the circuit is busy. Selection of more than one drop is, of course, possible by sending the proper office calls. After selection, Chicago and West Palm Beach have a direct, private connection and may use the circuit as long as desired. The same procedure is used to disconnect, except that no office calls are typed, causing all printers to return to the idle condition.

The major problem presented by this procedure from the multiplex point of view is the presence of the long open or spacing signal to initiate the call-in procedure. As mentioned before, the normal idle condition for a multiplex channel is a spacing signal, just the reverse from that of an idle printer on a landline facility. Fortunately, this kind of incompatibility can be resolved by a printer-to-multiplex (FRXD) translator, which is a commonly used connecting link between a landline and ocean cable channel, and an auxiliary electronic unit. By these means, it is possible to recognize the long "open" and convert the normal multiplex spacing into a different but recognizable combination to be decoded at the distant end where a translation from multiplex to printer (MXPX) is made to open the customer's line. Since an idle condition

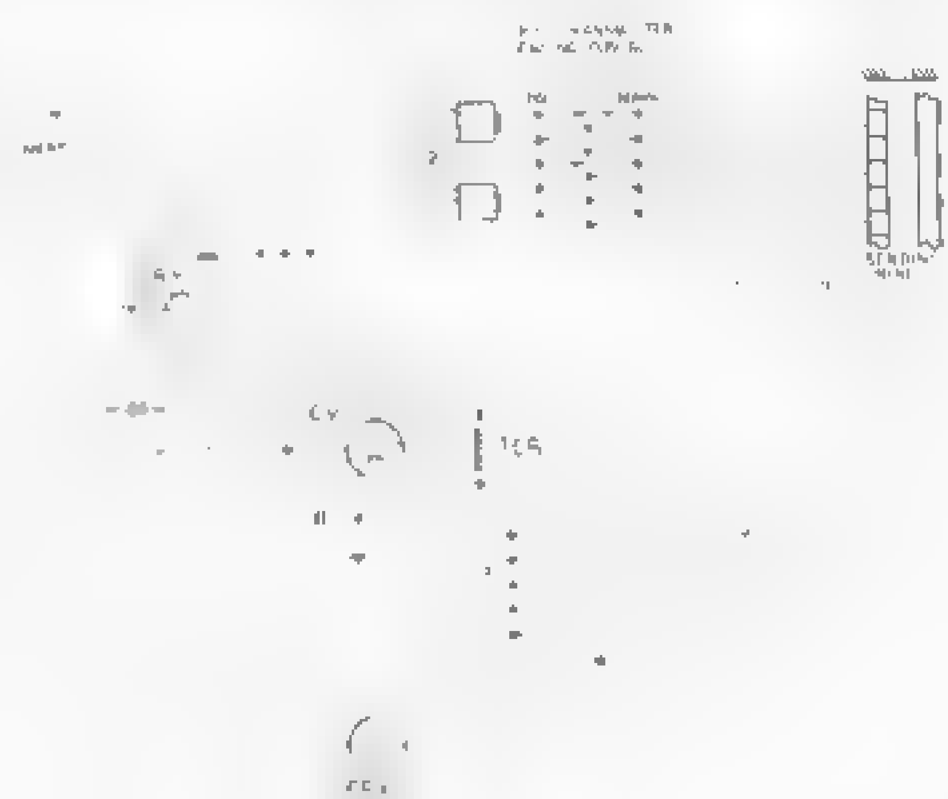

Figure 2. Selection repeater sending end theory

on the multiplex is represented by "blanks" on the channel transmitters (five code pins on spacing), the most easily recognized difference is marking for each of the five code pins (LTRS), also, it is the only character which should always appear singly in normal traffic operation. Reference to the theory of the sending end of the "selection repeater" shown in Figure 2 will illustrate how readily this was accomplished.

Sending End Theory

A low-impedance signal relay (LRY) of about 75 ohms impedance is inserted in series with the customer's leg circuit

This relay does not materially affect the operation of the customer's printer as it follows the line signals. Under idle or marking conditions for the teleprinter leg, this relay remains energized allowing the biasing condenser for a 6V6 vacuum tube to be charged negatively through 1000 ohms. The resulting negative bias on the grid of the tube cuts it off, and a transmitter control relay (TCRY) remains deenergized. The contacts of TCRY maintain spacing battery on the printer-to-multiplex (FRXD) transmitter's spacing sensing contacts, which represents the normal idle or spacing condition for the multiplex. Spacing battery will be either positive or negative depending upon the multiplex channel used.

When the customer's circuit is opened by the initial 5-second spacing control for way-station selection, the low-impedance signal relay (LRY) will remain deenergized, allowing the biasing condenser of the 6V6 to charge to positive battery through half a megohm and causing the tube to become conductive and energize the transmitter control relay. The time delay of approximately one-half a second, charging one microfarad through 500,000 ohms, allows for the operation of LRY when following normal teleprinter signals and distinguishes between the spacing pulses and the long open which precede a way-station selector customer's transmission. When operated, the transmitter control relay contacts reverse the battery on the FRXD transmitter's spacing sensing contacts and will cause the multiplex to transmit marking battery for each of the five code pins (LTRS combination).

A second set of contacts closes an FRXD "SELECTION OPERATE" lamp circuit giving a visual indication that the local customer's drop has initiated a way-station selection procedure. This condition is maintained for the duration of the long open until the teleprinter leg is closed and negative bias again operates the 6V6 vacuum tube to cutoff, releasing the transmitter control relay (TCRY) and restoring the FRXD to normal idle condition ready to translate the office call selector characters. All other functions of the FRXD equipment of course remain unchanged, allowing the equipment to operate in the normal manner.

Receiving End Theory

At the receiving end of the cable, the signals are distributed from the multiplex face plate to a multiplex-to-printer (MXPX) rack. The MXPX conversion must distinguish between a normal LTRS character in a message or occasional "doodles" with the LTRS key by an operator while composing her thoughts for the next sentence, and the long string representing the 5-second spacing interval of a way-station selection procedure. This procedure required the use of a novel transformer-coupled electronic reading device as shown in Figure 3 for the receiving end theory.

Resistances of 390 ohms are inserted in series with each of the five multiplex delivery segment circuits and are coupled through five primary windings of a transformer to the grids of a 6SL7 trigger tube. Each of these resistors passes current of either spacing or marking polarity as the brushes wipe over their respective segments, and pulse the control grids of the trigger tube. The transformer is so wired that a positive potential on the upper end of the primary windings will reflect in the secondary with the top of the winding (as shown in the figure) being positive with respect to the bottom. When LTRS (five marking or negative pulses for the particular channel illustrated) are received by the multiplex circuit, each of the delivery segments, as the brushes pass over it, causes a voltage drop across the series resistor so that the primary windings are each excited with a negative potential on the top.

This sequential application of battery to the primary windings reflects into the secondary biasing grid No. 1 to cutoff and grid No. 4 positively. Under these conditions, the potential of plate No. 5 is approximately 50 volts with respect to the cathode, and that of plate No. 2 is about 200 volts by virtue of the plate resistor circuits to positive 120 volts (240 volts over the cathode). A channel polarity relay (2CPRY) is introduced in series

with the MXPX channel polarity relay to correct for the different channel spacing polarities and for this condition is pulled up, connecting plate No. 5 of the trigger tube to the grid of the first 6V6 MXPX control tube (VT-1).

The 50-volt potential on plate No. 5 is not enough to fire the neon lamp, and the grid of the first control tube is biased to cutoff, allowing the one-half microfarad biasing condenser of the second 6V6 MXPX control tube to charge positively through two megohms. This condenser is allowed to reach a potential which is sufficient to cause the tube to be conductive energizing a printer control relay (PCRY). The time delay is necessary to permit the "selection repeater" to receive and recognize at least three successive LTRS characters before operating to energize the printer control relay (PCRY). When the PCRY is energized, its contacts short out windings of the MXPX cutout relay and output relay. This condition, by virtue of various operating circuits of the MXPX, maintains a spacing holding current through all relays of the MXPX. With the output relay's main windings shorted, it will be held on its spacing contact regardless of the operation of the other relays, and the customer's drop remains open for as long as only marking potential is scanned on the delivery segments. A third set of contacts on PCRY operate to light the MXPX "SELECTION OPERATE" lamp, indicating that the customer's drop has been opened.

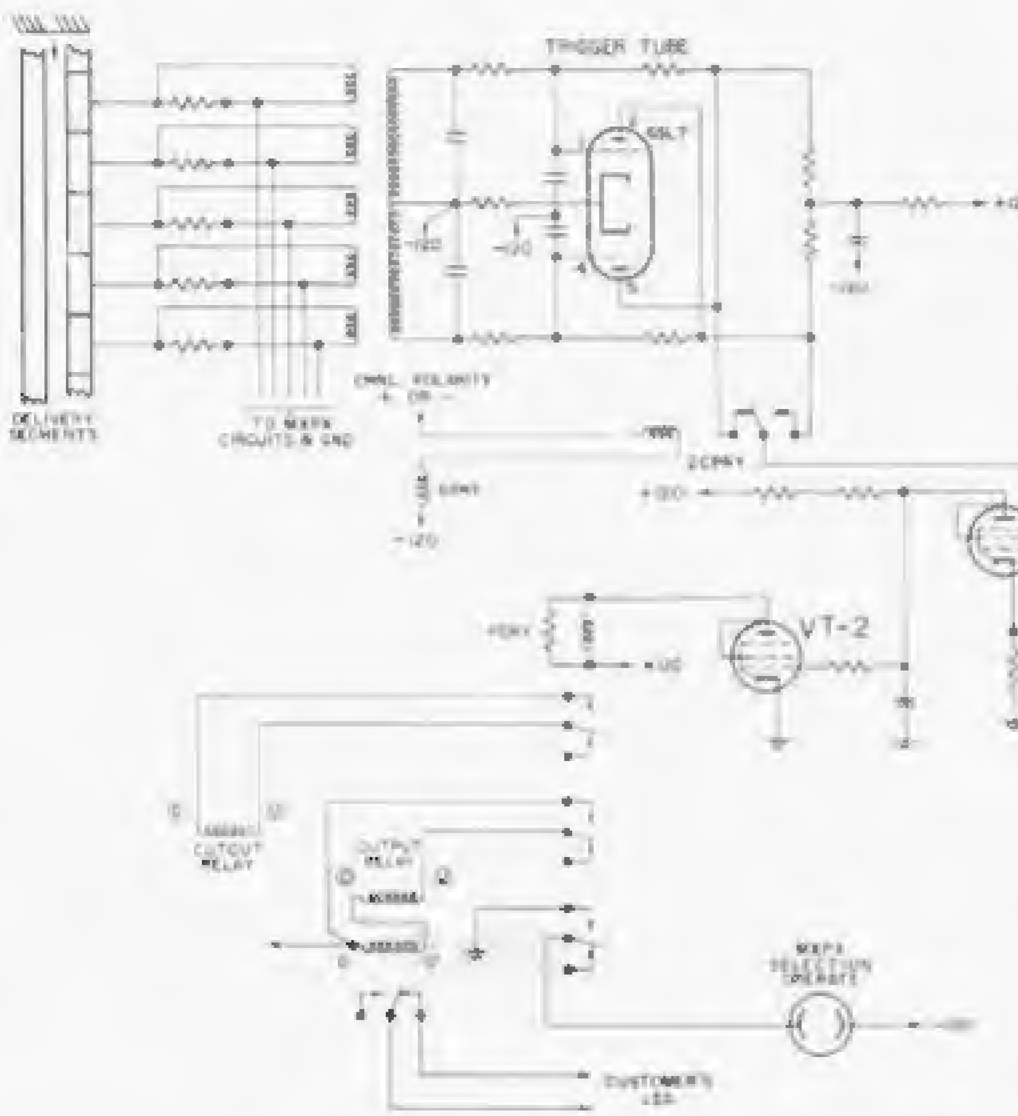

Figure 3. Selection repeater receiving end theory

Receipt of a single spacing battery (positive) pulse from any one of the delivery segments will reverse the polarity on the secondary for that pulse, causing a reversal of the action on the grids of the trigger tube. Plate No. 2 now is cut off, and Plate No. 5 conducting with a potential of about 200 volts with respect to minus 120. This voltage fires the neon

lamp, and causes the grid of the first MXPX control tube to be positive with respect to its cathode. This of course causes the tube to conduct, closing a path for the discharge of the second control tube biasing condenser. With each spacing pulse this condenser is discharged, consequently it can never reach the point where it will cause the second tube to conduct and the printer control relay (PCRY) remains deenergized. The usual MXPX functions are therefore unhindered and traffic or idle conditions continue in the normal manner.

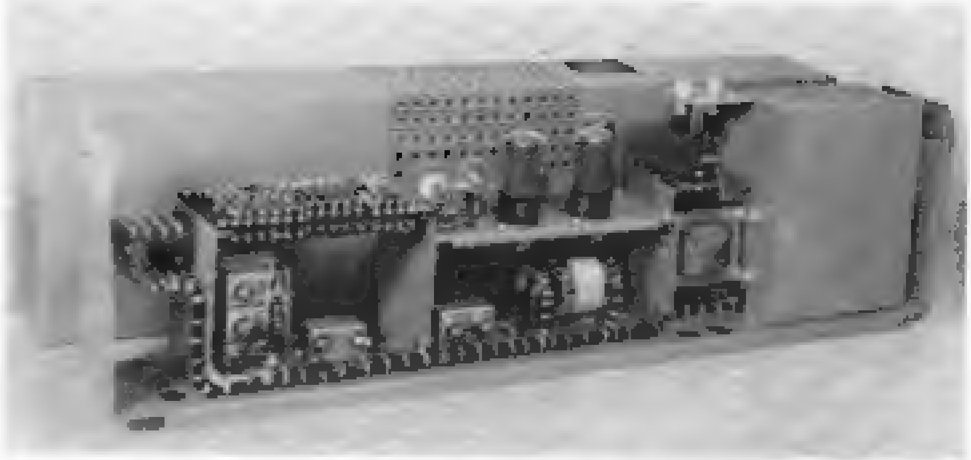

Photo R-10,192

Figure 4. Way-Station Selection Repeater 8015-A

Two Units Mounted on Single Chassis

These two circuits, the sending end and receiving end, are of course both required at each end of the multiplex circuit, and it was found convenient to mount the components on a single chassis which could be installed at the top of the FRXD-MXPX rack handling the channel to which the way-station customer was assigned. Figure 4 shows the completed panel which is known as a Way-Station Selection Repeater 8015; it resembles a standard repeater rack panel in all respects except for its dimensions which are 4 inches high, 29 inches long and 7 inches deep. This panel includes at the right-hand end a signal relay unit which encloses the three relays (LRY, TCRY and PCRY) required to control the sending and receiving multiplex. This signal relay, because of its horizontal mounting when installed on the FRXD-MXPX rack, had to be equipped with the tray-like detail to insure its being held in its socket.

Two of these panels were built and installed, one at the cable office, 40 Broad Street, New York, and the other at the far end of the multiplex circuit in Havana. Their use for the way-station customer provided such satisfactory service that when a newer multiplex of greater capacity was designed for NY-HAVANA, the circuitry for a selection repeater was incorporated as a part of the new racks. Of course, this method is not confined to cable applications, but is generally available wherever start-stop and multiplex circuits may beneficially be joined.

Reference

1. A Two-Channel Carrier Telegraph System for Short Submarine Cables, F. L. NEWELL and C. H. CRAMER, *Western Union Technical Review*, Vol. 4, No. 2, April 1950.

Mr. Krantz's biography appeared in the October 1955 issue of Technical Review.

Patents Recently Issued to Western Union

Facsimile Scanning Mechanism

D. M. Zabriskie

2,770,517—November 13, 1956

Adaptation to a multistylus facsimile recorder of a rubber-like belt having imbedded therein longitudinal metallic tension strands, and bearing cogs or teeth on the interior surface adapted to engage recesses in the surface of the molded pulleys. The stylus holders may be bolted or cemented to the belt while a metal contact bar provides electrical connection thereto and serves to maintain constant stylus pressure.

Self-Adjusting Auxiliary Bearing

R. Steeneck

2,783,100—February, 26, 1957

A self-adjusting auxiliary bearing structure in one embodiment of which the shaft is journaled in a sphere which is yieldably supported by a mating surface in a thick disc so as to permit angular adjustment of the shaft. In addition, the disc is slidable laterally in a close-fitting annular recess having a vacant peripheral space filled with silicone putty, asphalt or other like substance of such viscosity as to permit slow lateral adjustment to take place. The bearing is illustrated in connection with a teleprinter distributor shaft, but is applicable also to large shafts.

Facsimile Recorder

D. M. Zabriskie

2,783,120—February 26, 1957

A stylus belt guiding assembly adapted for high-speed recorders which includes a belt guide at the rear of the belt, a stylus guide in front of the belt along the route of the stylus travel, and an elongated leaf spring pressing on the top of the stylus mounts through the length of their travel. To reduce friction, the scanning run of the belt is placed in the approximate position which the belt assumes naturally under centrifugal forces. A stylus adjusting gauge is also incorporated.

Facsimile Transmitters

J. H. Hackenberg, G. B. Worthen,

G. H. Ridings

2,785,223—March 12, 1957

A keying tube adapted for operation by a stylus while scanning conductive marks on message copy. The control grid of the tube, normally biased to cut-off, is short-circuited to ground by the conductive marks on the copy to cause a large anode current to flow. By including the space path of a crystal controlled oscillator tube in series with the anode of the keying tube, a radio transmitter may be modulated. A low-pass filter may be incorporated into the keying circuit to reduce slightly the speed of response and hence reject background interference.

Multiple Stylus

W. E. Miller, F. G. Hallden

2,789,027—April 16, 1957

A turret accommodating a plurality of radially mounted styli is successively rotated one step by means of a pawl and ratchet mechanism as the turret is retracted at the end of a message. Hence for each succeeding message, the next stylus in line is successively presented, thus achieving uniform progressive wear. A separate geared-down motor advances the positioned stylus into contact with the paper.